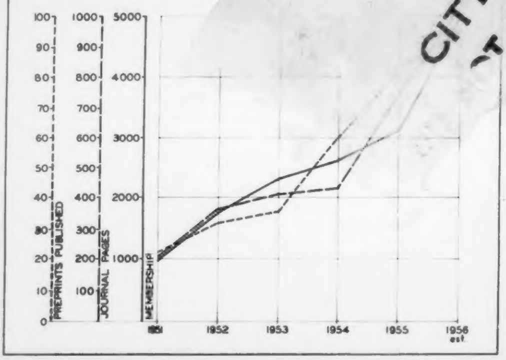
JET PROPULSION

Journal of the
AMERICAN ROCKET SOCIETY

Rocketry . . . . Jet Propulsion Sciences . . . . Astronautics

VOLUME 26 NOVEMBER 1956 NUMBER 11



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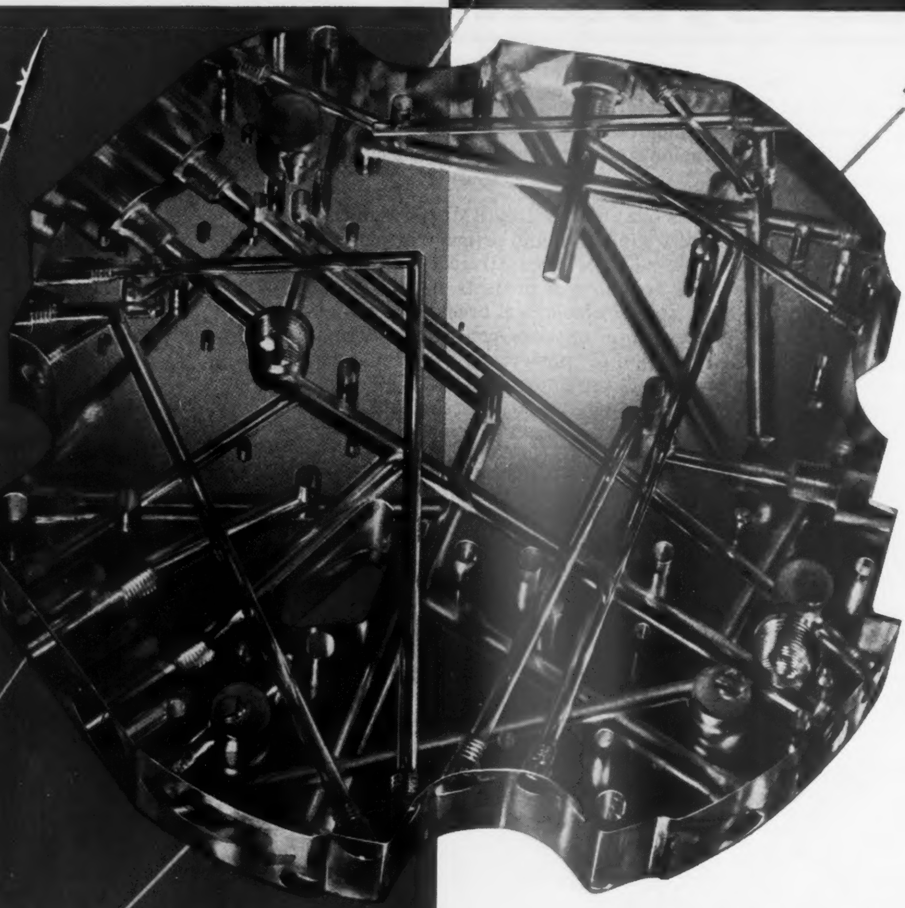

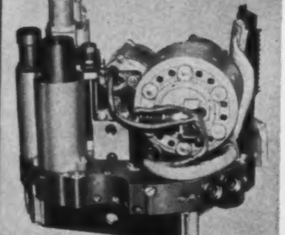

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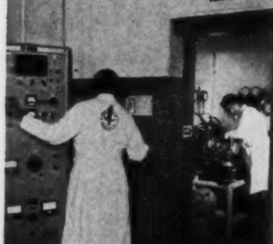

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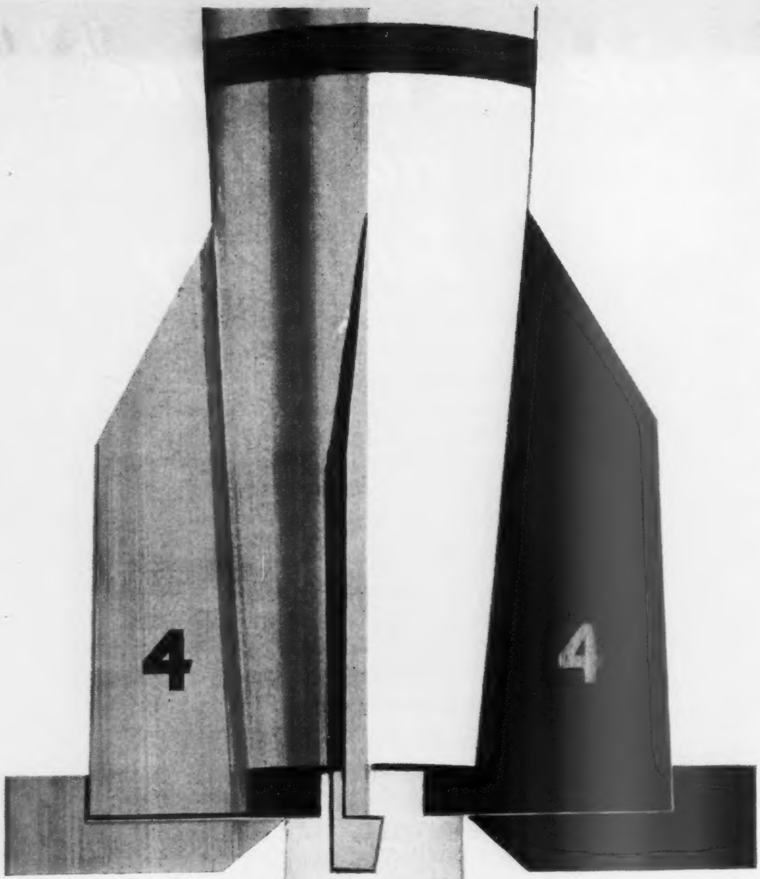
JET PROPULSION

Journal of the
AMERICAN ROCKET SOCIETY

JET PROPULSION, the Journal of the American Rocket Society, published monthly by the American Rocket Society at 20th and Northampton Streets, Easton, Pa., U.S.A. The Editorial Office is located at 500 5th Ave., New York 36, N. Y. Price $1.25 per copy, $12.50 per year: Entered as second-class matter at the Post Office at Easton, Pa., under the Act of March 3, 1879.



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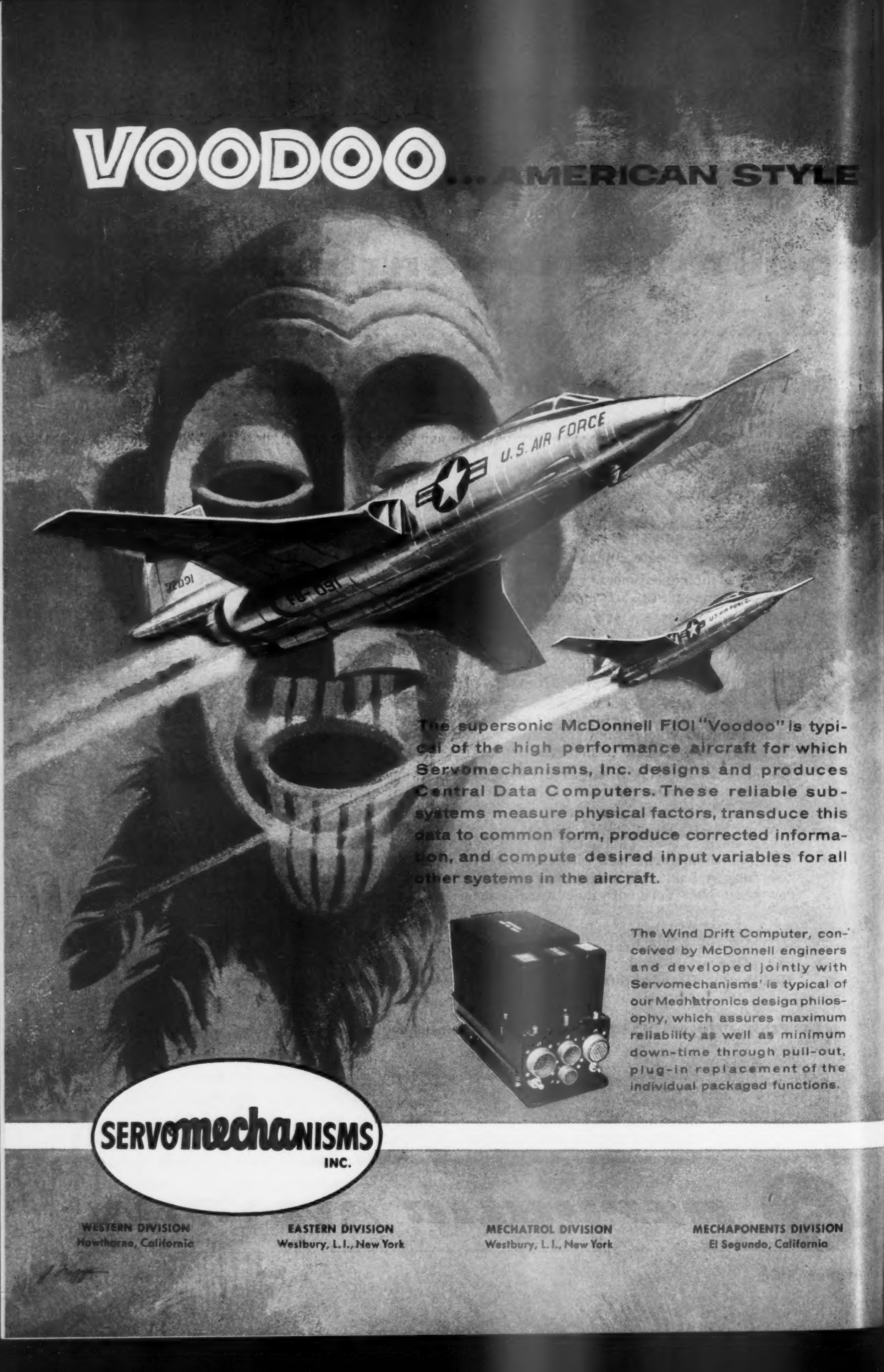

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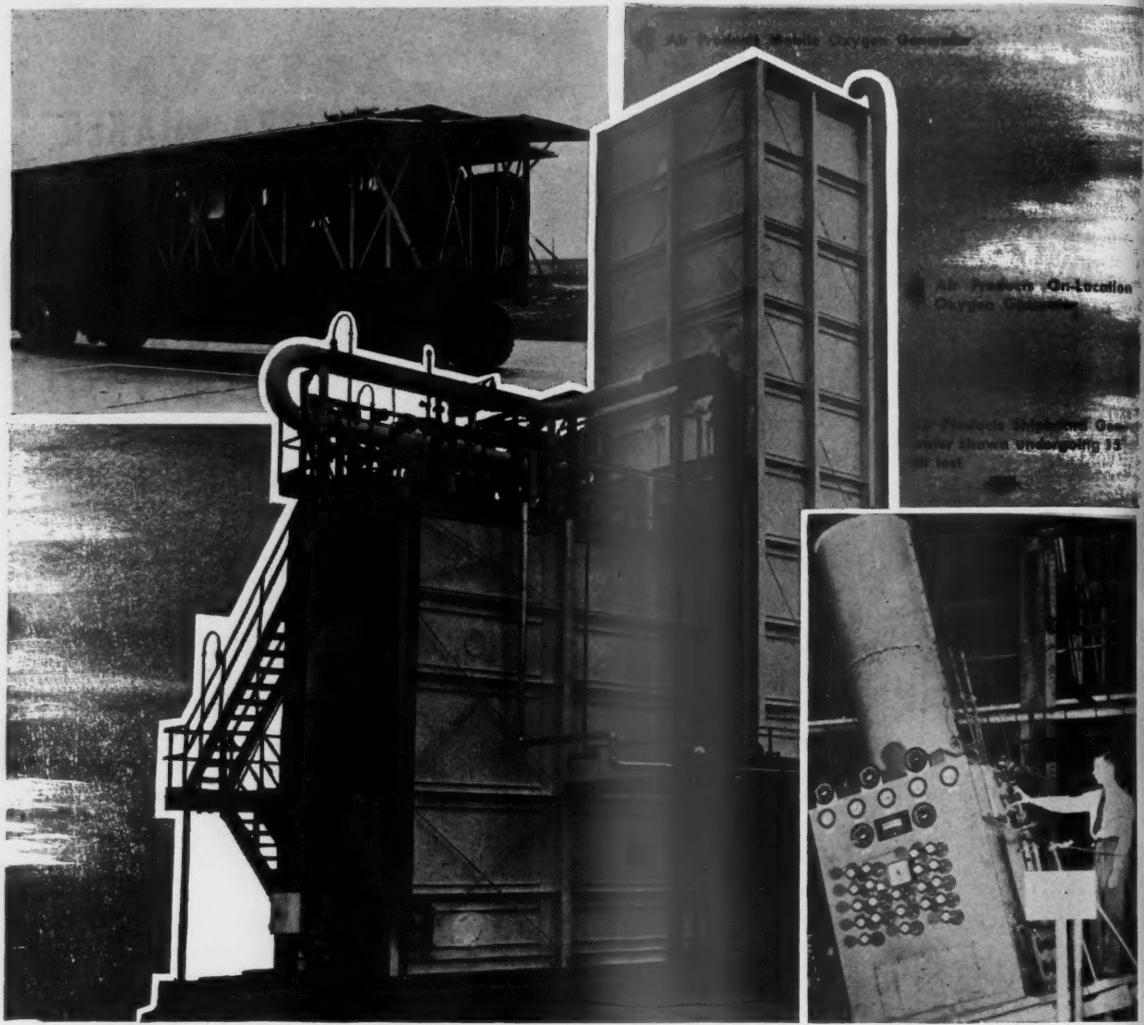

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NOVEMBER 1956

VOLUME 26 NUMBER 11

JET PROPULSION
Journal of the
AMERICAN ROCKET SOCIETY

Editor-in-Chief

MARTIN SUMMERFIELD

Basic Concepts of Space Law

ANDREW G. HALEY*

Explorations in space will necessitate drastic modification in today's legal principles governing man's relations with man. Science is rapidly outdistancing law in the field of space exploration and travel, and legal scholars must act forthwith if we are to avoid perpetuating the inadequacies of the international law of today in the space law of tomorrow. The body of modern international law is hostile from the standpoint of both private international law and public law—including civil rules as well as rules of warfare—to the problems of travel and existence in deep space. The development of the international law controlling activities in the air spaces above the earth today is discussed; a system of space law based on the principle of fundamental justice is explained and advocated; and steps which might be taken by existing international organizations—especially in the field of communications—are detailed.

1 Introduction

AT THIS time we have about as clear a vision of the space law that will prevail one or two centuries from now as Hammurabi in the 22nd Century B.C. might have had of our private and public international law of the present day. This is not said by way of minimizing the vision and prescience of that wise old lawmaker. Quite to the contrary, we should be encouraged to face the formation of space law in view of the legal framework Hammurabi and other great lawmakers constructed which, basically, has withstood the erosion of fourscore generations.

The point is that in the bleak beginnings of human civilization Hammurabi and Moses, and others, performed a very good job of laying down a set of ground rules for *homo sapiens*, a creature who has changed very little if at all during the eighty generations which back us up today. So thanks to the wisdom of the past, even in the realm of space law we are fairly competent to devise and promulgate rules and regulations to govern man qua man, even if at this time we can envision the legal parameters only as dimly as Hammurabi might have envisioned ours.

But what of the other intelligent and purposeful beings who may exist—what of our relationships to them? There is little evidence to indicate that there is other intelligent life in our solar system. But our own galaxy, the Milky Way, contains *forty billion* stars, many larger and some smaller than our own sun, and in Creation we know there are at least *forty billion* such galaxies. We know that one star has numerous planets. We know that our planet teems with intelligent beings. Is it probable, therefore, that other stars have planets, and other planets are inhabited by intelligent beings? What are the odds on these propositions? We may inquire of the man who believes that a personal God is the Creator of all things: "You believe that the world was created by God for His own glory, but do you believe that the manifestations of God's glory are confined to this one world and to mankind?" The lawyer may ask the questions but he cannot answer them. Implicit in the very statement of the questions, however, is the *possibility* that the answers may be affirmative. Much of this discussion will be premised on such possibility.

As we have said, in applying laws to man as man—wherever man may be—we can always preserve order with tried and true human sanctions; that is, we can always use force in shaping and controlling human conduct.

The use of humanly organized force, against other human beings, either as individuals or as integrated societies, no matter how small or how large such societies may be, has thus far overwhelmed our thinking. As we shall see later on, eminent publicists[1] have advocated the projection of modern international law as the basis for space law. But the body of international law is hostile, from the standpoint of both private international law and public law—including civil rules as well as rules of warfare—to the problems of travel and existence in deep space. Indeed, the first such projection might well imperil the earth satellite program unless there be drastic revision of existing rules of international law.

In any event, no concepts of human law, civil or criminal, which are designed to be enforced on human beings, may be projected for the government of other intelligent beings who dwell elsewhere in Creation.

In shaping the basic concepts of space law we must assume that other intelligent beings will not be identical to us; if it should happen that they are, we will be grateful for the simplification of the problems. We must be prepared to deal with intelligent beings who are *different in kind* from us and who live in environments *different in kind* from ours. It follows, therefore, that in the realm of space law, the principle of enforcement is *malum in se*. In dealings between intelligent beings who are different in kind, force could accomplish nothing but destruction.[2]

Although these propositions open great areas of juridical speculation, we leave them now, simply pointing out before we undertake to enforce our legal concepts on other intelligent beings as we have on the Indians (i.e., on the theory they could not withstand our force) that we should contemplate the hapless possibility that the situation might be reversed and we may turn out to be the savages who are decimated and enslaved.

The rejection of present-day international law as the basis of space law follows from an understanding of what that international law is. Hackworth defines international law as "a body of rules governing the relations between states. It is a

Presented at the ARS 25th Anniversary Annual Meeting, Chicago, Ill., Nov. 14–18, 1955.

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[1] The term "publicist" means: "One versed in, or writing upon, public law, the science and principles of government, or international law." Black's Law Dictionary, 3rd edit., 1933, p. 1464.

[2] These views will be implemented in detail in subsequent chapters dealing with such topics as (1) the rules of space flight and (2) regulation of space communications.

system of jurisprudence which, for the most part, has evolved out of the experiences and the necessities of situations that have arisen from time to time."[3]

Grotius was one of the first to attempt to codify international law. His 16th Century treatise on the law of war contains much of the basic material for modern international law. His work was "a manual of rules for making, conducting, and concluding war, in which, after such a cursory survey of the more general principles of morals as seemed to the author sufficient to illustrate the nature of law, and to establish the immutable distinction of right from wrong, he proceeds to inculcate the general adoption of the best usage introduced on these subjects in times then recent and to persuade all nations to pursue it by reasons of justice, by considerations of interest..."[4]

Modern legal writers, largely influenced by Grotius, regard international law as nothing more than positive law, i.e., law enacted *by a government* for the regulation of a society. In other words, the present-day concept of international law recognizes only those rules of law which are adopted by governments, which are accepted by the judges of courts of justice, which are applied by them in decisions of cases, and which enter into the judgments and are executed. As Hackworth says, international law possesses the characteristics "common to municipal law."[5] His meaning is illustrated by the law governing the air space *of the earth*. That law, as will be shown below, is based solely on each nation's absolute right of sovereignty over the space above its territory, a concept completely repugnant to the nature of our proposed travels in space.

In searching among the traditional philosophies of law for one more benign to space travel we should look to the writings of those publicists of the 15th and 16th Centuries who believed that international law should come from the law of nature. The present pertinence of the "natural theory" of international law is all the greater when we consider that it received its most searching examination at another time when man was faced with the problem of devising a new system of law upon the discovery of a new world.

The school of international law which maintains that natural law should be the basis for international law is said to have been founded by Francisco de Vitoria. By his definition, "the law of nations is the law which natural reason has established among all nations."[6]

Natural law, the keynote of Vitoria's philosophy, is a

> ...system of rules and principles for the guidance of human conduct which, independently of enacted law or of the systems peculiar to any one people, might be discovered by the rational intelligence of man, and would be found to grow out of and conform to his nature, meaning by that word his whole mental, moral and physical constitution.[7]

Natural law is not intangible and nonexistent, as followers of the positive school of law insist. It is not imposed by a sovereign or a legislature; it grew up before either existed. It does not exist in code form and has never existed in statutory form. "It is a state of mind, which is however a fact, that certain rights and certain duties were necessary in any and every society composed of human beings."[8]

Vitoria extended the principles of natural law and applied them to international law as a basis of cooperation in the world community. He was motivated to a great degree by the reports sifting back to Spain of the conditions in the new world and the shamefully bad treatment accorded the natives by adventurers interested only in gain. The success of the adventurers would have meant annihilation of the Indians. With this need, then, for a law to govern a nation's actions in new territory and in relation to other nations, Vitoria set forth his principles of international law.

The rule of the law of nations, "that what belongs to nobody is granted to the first occupant," said Vitoria, could not be applied to America, for the land was held in lawful possession by the Indians. He stated further that, "The Spaniards have a right to travel into the lands in question and to sojourn there, provided they do no harm to the natives, and the natives may not prevent them." The law of nations, which is either natural law, or derived from natural law, constitutes the basis for this rule, said Vitoria. Citizens of one state, then, could not be prevented from traveling or living in other states, "provided this in no way enured to their hurt and the visitors did no injury."[9]

Vitoria's system of international law is based upon association, a community of interdependent states, each possessing rights and reciprocal duties. "Nature has established," Vitoria adds, "a bond of relationship between all men."[10] He recognized the Indians as "States of the New World to which he would attribute the rights of States in the Old World."[11] Hence, the dominant group could not appoint its leader as the leader of the New World without the assent of the populace. Irrespective of size, form of government, or religion, all states were equal and independent in Vitoria's system.[12]

These principles were further extended by another Spaniard, Francisco Suarez. He accepted the basic tenents of Vitoria's work, but proceeded to make clear distinctions between natural law and law of nations. Writing after the death of Vitoria, he advocated an association of states and the adherence to laws in the association of states. The law of these states, Suarez says, comes about "in great part by natural reason, nevertheless not sufficiently and immediately for all matters; and therefore certain special laws could be introduced by the usage of these same nations..."[13] But, Suarez said, the basis of these special laws should be natural law, founded on reason, "the law everywhere existing among human beings in society, regulating the simple needs of its members and the rights and duties of society towards its members and itself." Natural law was to be distinguished from law of nations, however, for natural law is immutable and universal and originates from natural evidence, while the law of nations is changeable, not common to all, and of positive and human origin. The law of nations, applicable as it may be to the

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[3] He adds, "It has developed with the progress of civilization and with the increasing realization by nations that their relations inter se, if not their existence, must be governed by and depend upon rules of law fairly certain and generally reasonable Customary, as distinguished from conventional, international law is based upon the common consent of nations extending over a period of time of sufficient duration to cause it to become crystallized into a rule of conduct. When doubt arises as to the existence or non-existence of a rule of internationl law, or as to the application of a rule to a given situation, resort is usually had of such sources as pertinent treaties, pronouncements of foreign offices, statements by writers, and decisions of international tribunals and those of prize courts and other domestic courts purporting to be expressive of the law of nations." Hackworth, "Digest of International Law," Govt. Ptg. Off., vol. I, 1940, p. 6

[4] Sir James Mackintosh, "Dissertation of the Progress of Ethical Philosophy, Chiefly During the Seventeenth and Eighteenth Centuries," Miscellaneous Works, vol. I, London, 1846, pp. 49, 50.

[5] Hackworth, op. cit. supra, p. 5 at p. 1; see also Hall, "International Law," 8th edit., Higgins, 1924, p. 16.

[6] Scott, "The Spanish Origin of International Law," Georgetown University, 1928, pp. 33, 116.

[7] Black's Law Dictionary, 3rd edit., 1933, p. 1223. See also St. Thomas Aquinas, "Summa Theologica," I–II, 97, 1 and 1: "The natural law contains certain universal precepts which are everlasting whereas human law contains certain particular precepts according to various circumstances."

[8] Scott, op. cit. supra, p. 9 at p. 101.

[9] Vitoria, "De Indis et De Iure Belli Relectiones," printed by Carnegie Institution, Washington, D. C., pp. 139, 151.

[10] Ibid.

[11] Scott, op. cit. supra, p. 9 at p. 25.

[12] Vitoria rejected the Roman principle of extension of empire in "the cause of allies and friends" as a basis for granting Spain any territory or right in America. Scott, op. cit. supra, p. 9 at p. 38.

[13] Suarez, "De Legibus," II. xix. 9.

world community, is still founded on "probability" and the "common judgment of men."[14]

Suarez's great distinction was that natural law arises of "necessity from the nature of things by an evident and logical deduction from natural principles," its obligatory character being due to its natural source, and that it prohibits that which is evil *per se*, while the law of nations defines the evil in prohibiting it. The two legal systems, however, also have points in common. They are both "in a certain sense common to all people . . . they apply only to human beings and they both include precepts, prohibitions, and also certain privileges and permissions."[15]

Suarez envisioned as did Vitoria an international community composed of independent, perfect States bound by "a certain unity" with each "a member in a certain fashion of this universe, so far as it concerns the human race."[16] Such an international community was an outgrowth of state government, based upon the natural impulse of man toward social relationships, urging them to unite. This concept furnished the basis for the more impressive international community envisioned by Vitoria and Suarez, founded on the same basic precept.

Wars, colonialism, and strong nationalism throughout the world have overwhelmed the sound basis of international law for which Vitoria and others argued. Although phases of the law of nature and some principles of equity and morality are infused into it,[17] international law today is largely self-serving municipal law.

Natural law, Aristotle said, "is that which has the same authority everywhere, and is independent of opinion . . ." International law, as it has developed, is virtually the antithesis of natural law as thus defined. Since what is needed, above all, in evolving rules of conduct for the opening of the new frontier in space is a set of principles which are beyond national disagreement, it is evident that our space jurisprudence must be based upon something other than present-day international law.

This conclusion is aptly illustrated by the "international law" relating to rights in air space. This law is not international—it is a hodgepodge of strong laws of individual nations which assert absolute sovereignty over air space. There are a few pious declarations of international organizations hinting at the need for some sort of freedom of the air. But there is really no such freedom. We shall discuss this matter in detail because of its direct bearing on space flight and the unmanned satellite of the earth.

2 The Background—Sovereignty Over Air

Historically, the sovereign has always asserted exclusive, absolute dominion over the land and everything incident to the land, including the space above it. This is and traditionally has been the civil law, as well as the private and public international law. In England, for example, landowners were held to have extensive rights of ownership of the air and subsurface areas, but these private rights were *granted* by the sovereign. As will be pointed out later, the sovereign powers have withdrawn most of these rights in those instances where they originally existed. They were based on two fundamental maxims[18] of English common law which provided generally that private ownership of land extended from the earth indefinitely up to the sky and indefinitely down into the earth.[19] In any event, these private rights could be asserted only against other private citizens; the sovereign never parted with its paramount right to control the space above its territory.

International concern over the rights of governments in air space became significant at the beginning of the Twentieth Century—approximately the time of the Wright brothers' first flight. In 1902 the Institute of International Law, meeting in Brussels, considered a proposed convention on the regulation of aerial navigation, drafted by Paul Fauchille, and approved it at the 1906 meeting in modified form.[20] The convention would have made the air free to commerce and travel, just as is the sea. The provision for national security measures, while vague and indeterminate, was a reasonable reservation of sovereign rights to protect against civil negligence or hostile action through the air, but it was not intended that any nation should usurp the air completely.

The proposal was never implemented in an international convention. The proposal is significant, however, as being the first attempt at codification of the subject. It is also significant because it is one of the few times that the publicists have proposed "freedom of the air."

Further provisions expanding the 1906 proposal were adopted when the Institute met again in 1911. Fauchille and L. Von Bar prepared the basic document which required the marking of aircraft as to nationality of the country of registration.[21] Similar provisions have appeared in later international agreements on the utilization of air space.[22]

Fauchille's proposal was brushed aside by all nations during World War I. Each nation asserted its absolute dominion over the space above its land. For most countries the maintenance of neutrality required such action. The Kingdom of the Netherlands, on the air route between England and Germany, was especially vocal in warning belligerent aircraft away from the air over its territory and, on a number of occasions, it expressed the legal nature of its sovereignty over its air space.

In August 1914, the Netherlands interned a German hydroplane which had been forced down in waters near the coast of the Netherlands. The German Government took the position that the aircraft was like a warship because (a) it was attached to a warship, and (b) it was in itself a war vessel while in the water; and that as a warship it should be permitted, pursuant to international law of the sea, to be repaired within a certain time and then to leave the Netherlands area. The Netherlands rejected these contentions, saying

> . . . aeroplanes, including hydroaeroplanes, could not be considered warships. They are things sui generis which do not fall within the application of the articles of the Proclamation of Neutrality dealing with the treatment of warships. . . . *This attitude conforms to international law, especially since no special treaty provision exists with respect to the treatment of belligerent aeroplanes on the territory of a neutral Power.*[23]

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[14] Scott, op. cit. supra, p. 9 at pp. 92, 97.

[15] Suarez, op. cit. supra, p. 15 at p. 90.

[16] Suarez, op. cit. supra, p. 15 at p. 9.

[17] Hackworth, op. cit. supra, p. 5 at p. 3.

[18] "*Cujus est solum ejus est usque ad coelum.* 'Whose is the soil, his it is up to the sky.' Co. Litt. 4a. 'He who owns the soil, or surface of the ground, owns, or has an exclusive right to, everything which is upon or above it to an indefinite height.' 9 Coke, 54; Shep. Touch. 90; 2 Bl. Comm. 18; 3 Bl. Comm. 217; Broom. Max. 395. *Cujus est solumn, ejus est usque ad coelum et ad inferos.* 'To whomsoever the soil belongs, he owns also to the sky and to the depths. The owner of a piece of land owns everything above and below it to an indefinite extent.' Co. Litt. 4." Black's Law Dictionary, 3rd edit., 1933, p. 487.

[19] Cf., however, the dictum in Pickering v. Rudd, 4 Camp. 219, 221, 1815, that the flight of balloons over the property of others did not make the owners of the balloons liable to an action of trespass *quare clausum fregit*.

[20] 19 "Annuaire de l'Institut de Droit International," 1902; 21 id., 1906, 293, 297.

[21] 24 id., 1911, 23, 303.

[22] See p. 31, infra.

[23] (Emphasis supplied by the author.) Netherlands, Ministry of Foreign Affairs, Recueil de diverses communications du Ministre des Affaires Etrangeres aux Etats-Generaux par rapport a la neutralite des Pays-Bas et au respect du droit des gens, 1916, pp. 144–145.

The same rule was applied when the flight was not on a war mission. In 1915, the Netherlands interned a German aviator who had been engaged in a training flight and denied a request for release on the grounds that the nature of an airplane is such that it is impossible to determine whether its flight is warlike or innocent.[24]

The Netherlands Government protested a flight of German zeppelins over the Netherlands on Sept. 8, 1915, occurring because of navigational errors in foggy weather. The Netherlands note stated

> *Flying over the territory of a state without its consent is incompatible with respect for its sovereignty.*[25]

As a result of such incidents, in Dec. 1916, Germany agreed to the internment in Holland, for the duration of the war, of any airship and its crew landing on Netherlands territory.

As for the belligerent nations, there was no doubt that they assumed absolute dominion over their air space, usually asserted in a formal declaration. The United States, for example, was governed by the proclamation of President Wilson regulating civilian flying during World War I.[26]

After World War I the law of absolute sovereignty over air space was formalized in the Paris Convention for the Regulation of Air Navigation (1919) which provided that:

> ...every Power has complete and exclusive sovereignty over the air space above its territory.[27]

The Convention defined territory as national land area, colonies, and adjacent territorial waters.

The Paris Convention of 1919 also established other significant regulations on international flight pertaining to the rights of nations to air space. While granting "complete and exclusive sovereignty" to the individual nations, the Paris Convention required individual nations to observe the following conduct:

1 Aircraft of foreign nations have freedom of "innocent passage" over national territory subject to certain regulations.

2 Regulations made by the sovereign as to flights over its territory shall apply without distinction among nations.[28]

3 A sovereign may set up "prohibited zones" and foreign aircraft must not fly over such zones. In case of violation of such prohibitions, foreign aircraft must give the international distress signal and land promptly.

4 Nations which signed the Paris Convention may make separate, bilateral agreements on aerial rights with nonsigning nations. Such agreements must not conflict with the rights of the parties to the Convention.

5 The provisions of the 1911 meeting of the Institute of International Law as to aircraft registry and nationality were adopted in the Convention.

6 Military flights may not cross foreign air space without the permission of the sovereignty.

7 Transportation of munitions and explosives over foreign air space is prohibited.

The Paris Convention was an outgrowth of World War I. In the opinion of some it was an undesirable and unwise agreement reflecting wartime philosophy. Albert Roper, for example, condemned it as a "brutal suppression of the freedom of the sky, so dear to eminent jurists in the early years of the century..."[29] Nevertheless, the Paris Convention became binding on most of the nations of the world, and its philosophy is practically unchanged today.

The United States representative signed the Convention in 1920 with reservations permitting United States private aircraft to fly over "forbidden zones" in the United States, where foreign aircraft could not fly and further allowing the United States to make agreements with Canada and any nonsigning nations in the Western Hemisphere.[30] The Convention was not ratified by the United States Senate, however, because of the provision which placed its administration under the League of Nations to which the United States did not belong. Nevertheless, the United States observed the terms of the Convention on an unofficial basis.

As soon as the Paris Convention was signed the prohibitions against flight of aircraft of nonsigning nations over territory of the signers became burdensome. A protocol providing for exceptions to this provision was ratified and became effective on Oct. 27, 1922.

In 1923 the Commission of Jurists met at The Hague to prepare Rules of Aerial Warfare.[31] The Rules, which were not formalized as a treaty, provide that "Belligerent military aircraft are forbidden to enter the jurisdiction of a neutral State" (art. 40); a neutral government must "use the means at its disposal to prevent the entry within its jurisdiction of belligerent military aircraft and to compel them to alight if they have entered" and to "use the means at its disposal to intern any belligerent military aircraft" which has "alighted for any reason whatsoever, together with its crew and the passengers, if any" (art. 42).

The first major conference of private air law authorities after the end of World War I took place in Paris in 1925 when the International Technical Committee of Aerial Legal Experts (CITEJA) was created.

The sovereignty of the United States over its air space was declared in 1926 in the Air Commerce Act.[32]

In 1928 a general agreement was reached among nations of the Western Hemisphere at Habana.[33]

The signatories of the Habana Convention guaranteed each other "freedom of innocent passage" for private aircraft and forbade discriminatory regulations governing entry of foreign aircraft. The Convention also authorized bilateral agreements between signatories.[34]

The private international conferences on aerial law which had been instituted by Fauchille and others in 1902 were revived on a governmental level in the late 1920's and early 1930's. The Second International Diplomatic Conference on Private Air Law, held in 1929 at Warsaw, Poland, dealt with the liability of air carriers for death or injury to passengers or damage or destruction of property.[35] A Sanitary Convention for Aerial Navigation, concluded at The Hague in 1933, prescribed action to be taken by aircraft upon detection of various diseases in international flight.[36]

The Third International Conference on Private Air Law (Rome, 1933) adopted rules limiting the right to attach air-

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[24] Id., pp. 139–140.
[25] Id., pp. 135–138.
[26] See, e. g., President Wilson's proclamation of Feb. 28, 1918, appended to § 1042a, U. S. Comp. Stat., 1918 edit., embodying Title I, § 1, Chap. 30 of the Espionage Act of June 15, 1917.
[27] 11 League of Nations Treaty Series, 1922, pp. 173–310.
[28] See p. 32, infra, for modification insisted upon by the United States.
[29] "Recent Developments in International Aeronautical Law," *Journal of Air Law*, I, 395.
[30] Telegram from Secretary of State Colby to U. S. Ambassador Wallace in Paris, no. 722, April 9, 1920. MS. Dept. of State file 579, 6D1/486.
[31] See Commission of Jurists to Consider and Report Upon the Revision of the Rules of Warfare (The Hague, 1923); Moore, "International Law and Some Current Illusions and Other Essays," 1924, 182 et seq.; vol. I, pp. 45–46, "Digest of International Law," Govt. Ptg. Off., 1940.
[32] Stat. 1028, 49 USC par. 176.
[33] Treaty Series 840: 47 Stat. 1001.
[34] Id., Article IV. The first bilateral agreement on air navigation entered into by the United States was with Canada in 1929. Ex. Agree. Ser. 2. Agreements have also been entered into with Italy, Germany, Sweden, Norway, South Africa, Denmark, Great Britain, the Irish Republic, Liberia, and France, among others.
[35] Treaty Series 876, 49 Stat. 3000.
[36] Treaty Series 901, 49 Stat. 3279.

craft for debt and limiting liability for injuries by aircraft. The United States Senate did not ratify the Rome convention.

In 1938 the United States enacted the Civil Aeronautics Act, amending somewhat the assertion of sovereignty over air space which was made in the Air Commerce Act of 1926 and providing for the flight of commercial aircraft of foreign nations over the United States in accordance with authorizations issued by the Civil Aeronautics Board (then the Civil Aeronautics Authority).[37]

In 1939 President Roosevelt issued an Executive Order regulating the flight of aircraft in the Canal Zone. This assertion of jurisdiction over air space in the Canal Zone area was immediately challenged by a Panama Court which held that the Republic of Panama had sovereignty over the air space.[38] The United States Department of State replied to this holding by pointing out that the United States had traditionally assumed jurisdiction over the air space in the Canal Zone area pursuant to well-established international law. Panama conceded, and the United States' sovereignty over the Canal Zone air space has not been challenged since that time.

The beginning of the Second World War in 1939 and the vital role played by aircraft in that conflict gave tremendous emphasis to the legal rights of nations to the air space above their territories. This was particularly important to the neutral countries. The general rule was that belligerent aircraft could not enter the domain of a neutral country—and that domain included the air space above the land and above the adjacent territorial water. The republics of the Western Hemisphere adopted a general declaration of neutrality at Panama on Oct. 3, 1939, denouncing "as a contravention of their neutrality any flight by the military aircraft of a belligerent state" over their territory.[39] Press reports at the time indicated that Germany was claiming the right to fly over territory of the Netherlands and Belgium at a height in excess of three miles, acting on the theory that national sovereignty over the air spaces is limited to a distance equal to the maritime territorial belt.[40] The Netherlands rejected this proposition, claiming sovereignty over its air space to "any altitude."[41]

Toward the end of the Second World War a Convention on International Civil Aviation was concluded in Chicago, Ill., declaring that "every state has complete and exclusive sovereignty over the air space above its territory.[42] The term "territory" was defined as "the land areas and territorial waters adjacent thereto under the sovereignty, suzerainty, protection or mandate of such state."[43] The Convention further declared in Article 8 that "No aircraft capable of being flown without a pilot shall be flown without a pilot over the territory of a contracting state without special authorization by that state and in accordance with the terms of such authorization." This clearly applies to guided missiles, pilotless aircraft, and unmanned earth satellites, but only if operated as civil aircraft.

This most recent major international agreement concerning civil aviation has been ratified by sixty-six nations and is in force today. Among the nations which have not ratified the Convention are USSR, Communist China, Hungary, and Bulgaria.

The International Air Transport Agreement was drawn up simultaneously with the Chicago Convention in 1944, and was subsequently ratified by seventeen states.[44] Under this agreement, commonly referred to as the "Five Freedoms Agreement," the contracting states granted each other in respect to *scheduled international air service* by civil aircraft the privilege of transit without landing.[45] Each of the contracting States maintained complete sovereignty over the air space above its territory and territorial waters.

Several writers on the subject of International Law, commenting on the Chicago Convention on International Civil Aviation, regard the doctrine of absolute sovereignty over air space as one which is firmly imbedded in international law, and which "may certainly be now accepted as the primary rule of the International Law of the air, and must be considered by any world organization."[46]

We have used the terms "space above the territory," "air space," and so on, indiscriminately in the foregoing historical summary. We use the terms as they have been used in the various unilateral or multilateral declarations which make up the stuff of our international law. Each such declaration, regardless of the term used, is designed to avoid injury or threats of injury to the declarant and his territory. The purpose is to prevent the flight over declarant's territory—at whatever height—of any man-made thing which may harm him or spy upon him. From this point of view the height of the forbidden space is to be determined functionally from the nature of the flight. That, in our view, is inherent in the modern concept of sovereignty over space. Professor Westlake expressed a similar view at the 1906 Institute of International Law. He "assumed that the State had territorial rights in space as high as flight could exist, but at the same time he assumed that such flight must take place in what he termed 'airspace.' "[47]

In the last few years the concept of the "aeropause" has been developed. The term arises as a biological and physical, rather than political or juridical, concept. "As the word suggests, it designates the altitude at which the atmosphere ends and space begins insofar as they affect the pilot and vehicle."[48]

It is obvious that jurisdiction over regions beyond the atmosphere will be claimed at least until each interested nation has successfully launched manned satellites into the aeropause area and returned them to Earth. For example, the United States at the present time forbids the aerial photographing of certain governmental installations, and the law does not exempt such photographing because of any height factors that might be involved.[49] And, as we have already observed, the International Civil Aviation Convention forbids the unauthorized passage of a pilotless aircraft "over the territory of a contracting State" without limitation as to height.[50]

3 The Unmanned Earth Satellite

In the light of the untrammeled nationalist sovereignty inherent in our rules of international law, the inauguration of the

[37] 52 Stat. 973, 49 U.S.C. § 176.

[38] Resolution, Sup. Ct. of Panama, 1st Jud. Dis., Feb. 22, 1939.

[39] Report of the Delegate of the United States of America to the Meeting of the Foreign Ministers of the American Republics, held at Panama Sept. 23–Oct. 3, 1939 (Department of State, Conference Ser. 44, 1940) 55–56.

[40] See Note by Kuhn in 34 A. J. I. L. (1940) 104.

[41] The Minister of the Netherlands (Loudon) to the Under Secretary of State (Welles), Sept. 5, 1939, MS. Department of State, file 740.00111, European War 1939/600.

[42] Convention International Civil Aviation, concluded at Chicago in Dec. 1944.

[43] Id., Article 2.

[44] Subsequently, six of the contracting states withdrew their ratification of the agreement and at present only eleven states are still parties to the agreement.

[45] International Air Transport Agreement, 1944, Article I (1).

[46] John C. Cooper, "Air Transport and World Organization," 55 *Yale Law Journal* 1195. See also Charles S. Rhyne, "International Law and Air Transport," 47 *Michigan Law Review* 43.

[47] Cooper, "High Altitude Flight and National Sovereignty," 4 *International Law Quarterly* 3, July 1951, p. 412.

[48] Ordway and Canney, "The Respectability of Astronautics as Reflected by Recent Developments in the United States," a paper read at the Fifth International Astronautical Congress, Innsbruck, 1954.

[49] Executive Order no. 10104, Feb. 1, 1950, 5 F.R., 597.

[50] See also, Fixel, Rowland W., "The Law of Aviation," 3rd edit., p. 70, The Michie Company, 1948; NcNair, Sir Arnold Duncan, "The Law of the Air," 2nd edit., Kerr and MacCrindle, p. 32, Stevens and Sons, Limited, 1953.

unmanned earth satellite program stands out as perhaps the most felicitous incident of the generation. The entire program could have been stopped by the protest of a solitary sovereign nation over which the satellite might pass, or endlessly delayed by detailed international negotiations. The inauguration of the program in a peaceful and uncomplicated manner is a great achievement of scientists throughout the world. The background of this epochal event deserves detailed commentary.

The program that was published in Aug. 1955,[51] was prepared by the United States National Committee for the International Geophysical Year, its Technical Panels in the various IGY disciplines, and its Secretariat. The public was informed that international cooperation in the study of our physical environment is not new; that the importance of geophysical data gathered over relatively remote areas of the earth was recognized in the last century in the conduct of the First International Polar Year in 1882–1883, when meteorological, magnetic, and auroral stations were first established in Arctic regions; that a Second International Polar Year was held in 1932–1933, fifty years later; and that these two international endeavors contributed greatly to our knowledge of the earth's magnetism and of the ionosphere.

The mission of the USNC-IGY is to assemble and study data from all parts of the world on such subjects as solar activity, longitude and latitude, glaciology, oceanography, meteorology, geomagnetism, aurora and airglow, ionospheric physics, seismology and gravity, cosmic rays, and upper atmosphere rocket studies, including the use of instrumented satellite vehicles. Because of the inherently global nature of these studies, the Aug. 1955 Report points out, the effort must be conducted "on a coordinated basis by fields and in space and time so that the results secured not only by American observers, but by participants of other nations, can be assembled together in a meaningful manner."

The Special Committee for the International Geophysical Year (French abbreviation: "CSAGI"), the international body of which the USNC-IGY is a constituent, held its first plenary seminar in 1953. Initially, the CSAGI did not provide for a Rocket Group. The importance of upper atmosphere investigations was emphasized at the XIth General Assembly of URSI at The Hague, Aug. 23 to Sept. 3, 1954.[52]

Commission III of URSI adopted a resolution recognizing "the extreme importance of continuous observations, from above the E-region, of extraterrestrial radiations, especially during the forthcoming International Geophysical Year" and pointing out that "an extension of present isolated rocket observations by means of instrumented earth satellite vehicles would allow the continuous monitoring of the solar ultraviolet and X-radiation intensity, and its effects on the ionosphere, particularly during solar flares, thereby greatly enhancing our scientific knowledge of the outer atmosphere."

Following the URSI resolution, CSAGI held a meeting in Rome, Sept. 30 to Oct. 4, 1954, at which a Rocket Group was formed and a Rocket Program outlined. The official Minutes of the Rocket Group [Working Group XI] contain the following entry:

> In view of the great importance of observations during extended periods of time of extraterrestrial radiations and geophysical phenomena in the upper atmosphere, and in view of the advanced state of present rocket techniques, CSAGI recommends that thought be given to the launching of small satellite vehicles, to their scientific instrumentation, and to the new problems associated with satellite experiments, such as power supply, telemetering, and orientation of the vehicle.[53]

The world was gratified to receive the news on Friday, July 29, 1955, that an earth satellite program would be launched under the auspices of USNC-IGY. The International Astronautical Federation convened in Copenhagen two days after the announcement and cabled President Eisenhower:

> The I.A.F. regards this undertaking as one of highest importance and an assured step in the evolution from aeronautics to astronautics.
>
> We are particularly happy at the announcement that the scientific data obtained will be available to all nations as testimony of the peaceful application of rocket technology for the benefit of all mankind.[54]

The Associated Press reported that "Nikita S. Khrushchev, First Secretary of the Soviet Communist party, said that if President Eisenhower's earth-satellites program is 'in the interests of mankind, then the Soviet government is always prepared to support it.' "[55] Two months earlier, the Russians had announced the organization of their own "Interdepartmental Commission for Interplanetary Communications."

As we have seen, July 29, 1955, was a momentous day in history. But under the principles of existing international law, any sovereign state could have nipped it in the bud. It could have announced that the launching of a man-made earth satellite to pursue an orbit over its territorial domain would constitute an act of war. It could have insisted that the very planning and inception of such a program required preliminary international agreement. But none complained, none protested, and the program is proceeding.[56] The scientists have benefited mankind as a whole in a field where the lawyers might well have failed.

The foregoing discussion serves to focus attention on the views of two eminent present-day publicists, John C. Cooper of the Institute of Advanced Studies and Oscar Schachter, Director of the General Legal Division, United Nations.

Schachter's view is that national sovereignty should extend as high over the land "as the atmospheric elements necessary to 'lift' aircraft."[57] Cooper's idea of the reasonable rule is to extend the sovereignty of each state "as far as their scientific progress . . . permits each state to control space above it."[58]

Schachter's rule is unrealistic in that the atmosphere or the ability to "lift" an aircraft has no critical reference to the prob-

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[51] Proposed United States Program for the International Geophysical Year 1957–1958, Aug. 1955.

[52] Report to the National Research Council, USA National Committee of URSI on the XIth General Assembly of URSI at The Hague, Netherlands, Aug. 23–Sept. 3, 1954, submitted to William W. Rubey, Chairman, National Research Council, Oct. 18, 1954, by A. H. Waynick, Chairman, USA National Committee of URSI.

[53] Since 1952, the American Rocket Society had been advocating that the National Science Foundation of the United States undertake studies of a satellite program and, in most respects, the programs recommended were parallel to those of URSI and CSAGI. Jet Propulsion, vol. 25, Nov. 1955, p. 631.

[54] Minutes of the Sixth International Astronautical Congress, Copenhagen, Aug. 1–6, 1955.

[55] New York *Herald Tribune*, Paris edit., Aug. 2, 1955.

[56] It is recognized, of course, that the apparent acquiesence of some states may change to recalcitrance. One commentator observes, for example, that "the communist world" is "dourly skittish about" foreign objects passing overhead. He notes that the USSR "has created sharp issues over American weather balloons passing above Soviet territory," and asks, "How much more might the Soviets object to satellites loaded with the latest observational equipment?" Yeager, "Outer Space Rights Puzzle World," *Nation's Business*, April 1956, pp. 40, 41.

[57] "Legal Aspects of Space Travel," 11 *Journal of the British Interplanetary Society* 14, Jan. 1952.

[58] "High Altitude Flight and National Sovereignty," 4 *International Law Quarterly* 3, July 1951, p. 419. (Author's Note: Several months after I wrote this paper Professor Cooper, in a memorable speech before the Institute of International Affairs in Washington, made certain assertions which have convinced me that I have herein misunderstood his earlier writings.)

lems of space. Cooper's rule presents the disquieting prospect that a state with extraordinary scientific resources could extend an empire into deep space. It is a counterpart of the "might makes right" principle which pervades maritime law and which kept England the mistress of the seas for centuries. Yet both rules have at least this to recommend them: they impose some limit over national sovereignty, Schachter's a nominative limit[59] and Cooper's an obviously empirical one. The importance of having any limit, no matter how distant, becomes apparent when we consider that we dwell on the surface of a sphere, so that perpendiculars drawn to the borders of a state would not be parallel, but would diverge into space as a "hypothetically infinite...funnel of dominion."[60] Anything which limits these awesome vistas is desirable.

The very nature of the problem is such that all human beings are directly and intimately involved in its solution. It may well be that there is no forum presently existing or ever envisioned which can cope with the problem in the best interests of all humanity. The League of Nations failed, and the United Nations may topple. But when problems persist, solutions have a way of emerging.

In the meantime, our only recourse is to work with the tools at our command. The United Nations should set up a Commission to study the legal and jurisdictional questions and an effort should be made to reach an understanding among all nations on those questions. Through the United Nations or by multilateral treaty-making, the principles should be established, as an *interim proposition*, that whereas each State may bar the passage of unfriendly high altitude rockets and satellite vehicles, none may prevent the passage of rockets and vehicles conducting scientific investigations, although the latter must conform to rules of safety adopted by conventions. Under no conditions should familiar parameters of jurisdiction be claimed, either by individual States or by the United Nations, over the area beyond the aeropause.[61]

These principles must necessarily have only interim application, for there must be a basic principle that the regions beyond the aeropause may be claimed by no nation; mankind may make only such utilization of space as will be for the benefit of all mankind and to the detriment of no other intelligent creature.

4 Communications Laws and Controls

In our present state of knowledge, scientific attainments, and communications techniques, the only means of guidance to and communication with the aeropause and beyond must be by radio. Other means of imparting intelligence and of earth control and remote control undoubtedly will be devised under the impetus of positive requirements. But solutions which will be found in centuries to come do not minimize the problems of the present day.

The problems of remotely controlling an unmanned earth satellite, either from earth or from some spatial point, and of automatically imparting knowledge through instrumentation in the satellite and on earth by use of radio spectrum are comparatively simple. We must remember, however, that the day is not very distant when those problems will multiply tremendously. With the advent of the manned satellite, all the problems of communicating intelligence will become quite complicated and will call for more and more use of the radio spectrum. Later, with the tremendous achievement of free flight in deep space will come immense communications problems.

The space use of radio has been discussed in many articles. We refer here only to four: Wernher von Braun's "The Mars Project";[62] John R. Pierce's "Orbital Radio Relays,"[63] supporting the Third Report of the Space Flight Committee of the American Rocket Society; George O. Smith's article in the *Journal of the British Interplanetary Society*;[64] and the chapter on "Communications" in Arthur C. Clarke's "Exploration of Space."[65]

Von Braun dispels any fear that radio will not be able to reach far enough into space to be effective. He points out that the U. S. Army in 1946 recorded radio waves reflected from the moon and concludes that "a powerful transmitter in space would have no trouble being received on earth, even at a distance many times that between earth and moon." He says that frequencies in the 10 cm (3000 mc) band are the most desirable because of the "lower power required" and the "wider bandwidth" which may be utilized. Von Braun had computed the minimum bandwidth required for operation in the 3000 mc range as 600 cps, which he says is about the narrowest band which would be useful for communication purposes in space flight.

As to equipment, Von Braun says that "unusual output power is developed by...the Magnetron in the 10 cm band" which can reach Mars with ease. In fact, existing equipment could reach beyond Mars. This excessive or "reserve range" permits the communication system to be modified so as to reduce equipment weight, or to transmit speech and music, with hand key communication reserved for extreme ranges.

Pierce believes that the earth satellite program will aid transoceanic communications on earth. He envisages two systems: "one consists of enough spheres [satellites] in relatively near orbits so that one of them is always in sight at the transmitting and receiving locations. The sphere isotropically scatters the transmitted signal, so one has merely to point the transmitter and receiver antennas at it to complete the path." His second proposed system is a single satellite 22,000 miles above the earth, and visible to all inhabited areas. The actions of the sun and moon on this satellite would necessitate remote control and periodic reorientation from earth. A 5-mc television channel to be carried by the single satellite system would require a 1000-ft sphere repeater and 10,000,000 watts power on earth. The same channel carried by a system of low level satellites would require only 100,000 watts.

Smith recommends a teletype system of transmission in the earth-to-moon link as the most accurate means of communication; for an orbital station-to-earth link, he suggests both audio and teletype systems. There will be no reflections or refractions in space, such as those that limit terrestrial communications, since radio travels in straight lines through a transparent medium. Galactic noise is not of a high level and the spectrum is spotty, Smith says, and therefore a convenient gap can be used for space radio. All problems in space communication seem to lie, then, below the first 500 miles of altitude.

The teletype system of space communications for this interplanetary network in the initial stages of space travel will be used primarily for transfer of technical data and instructions

(*Continued on page 968*)

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[59] Schachter notes that his suggested limit "would be in keeping with the purpose and intent of the treaties relating to aviation, which have thus far defined the upper limits of state sovereignty." Supra note 92.

[60] Ball, "Shaping the Law of Weather Control," 58 *Yale Law Journal* 213, 236, 1949; see also Jenks, "International Law and Activities In Space," 5 *International and Comparative Law Quarterly* 99, 103–104, 1956. The area at the mouth of the "funnel" would increase in proportion to the square of the distance from the earth.

[61] The earth satellites now in preparation must obviously be excepted from this prohibition.

[62] University of Illinois Press, 1953.

[63] Third Report Space Flight Committee, ARS, 1953.

[64] 12 *Journal of the British Interplanetary Society*, Jan. 1953, p 13.

[65] Harper & Brothers, 1951.

Effect of Vibrations on the Motion of Small Gas Bubbles in a Liquid[1]

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If a transparent test tank partially filled with water is strongly vibrated, small gas bubbles originated by surface disturbances appear in the lower parts of the vessel. These bubbles do not rise to the surface as would be expected from their buoyancy, but perform vibratory motions at the bottom or at the sides of the tank. As the rocket engine of a missile causes heavy vibrations, the possibility of the occurrence of similar bubble phenomena in fuel tanks is worth consideration. The present paper is a step toward an explanation of the complicated phenomena observed in the test tank. The basic equations for the motion of small gas bubbles in an inviscid liquid in the presence of harmonic vibrations are derived, and the mechanism which may make bubbles move contrary to gravity forces is explained. Applying the theory to cylindrical tanks, it is found that for sufficiently strong vibrations there are regions in the tank in which bubbles move downward and, further, that there are points where bubbles will collect. The paper does not treat all the phenomena observed in the test tank; e.g., the important question of the creation of the bubbles at the surface is left for future work.

Nomenclature

a	=	reference (nominal) radius of bubble
$C, \bar{C}$	=	coefficients in Equations [39, 41] defining the acceleration in an elastic vessel
$f = f(h,r)$	=	distribution of the applied dynamic pressure (Eqs. [29, 39])
g	=	gravitational constant
h	=	depth of bubble below surface; specifically, depth at which bubble oscillates without rising
I_0	=	modified Bessel function
M	=	total mass of fluid in vessel
N	=	number defining the applied acceleration $\ddot{x} = Ng \cos \omega t$
p	=	gas pressure in bubble
p_0	=	ullage pressure in vessel
p_1	=	$p_0 + hg$ static pressure at depth h
$\bar{p}$	=	dynamic pressure due to vibration
P	=	potential energy
r	=	radial coordinate (Fig. 4)
R	=	radius of cylindrical tank
t	=	time
T	=	kinetic energy
u	=	vertical component of fluid velocity $\vec{v}$
$\vec{v}$	=	velocity (vector) of a fluid particle
v	=	volume; specifically, volume of bubble
$x(t)$	=	displacement of vessel with respect to a reference line
$z(t)$	=	relative depth of bubble below the surface which moves with the velocity $\dot{x}(t)$
$\dot{z}(t)$	=	relative velocity of bubble with respect to fluid in vessel
α	=	coefficient defining the change Δ of the bubble radius (Eq. [16])
γ	=	ratio of specific heats of gas
Δ	=	increase in bubble radius above the reference radius a (Fig. 3)
μ	=	coefficient pertaining to elastic cylindrical tank (Eq. [39])
ρ	=	density of fluid
$\xi = z - h$	=	depths of bubble below level h
$\dot{\xi} \equiv \dot{z}$	=	relative velocity of bubble with respect to fluid
ω	=	circular frequency of applied acceleration $\ddot{x} = Ng \cos \omega t$
Ω	=	circular frequency of bubble of radius a at depth h (Eq. [13])

1 Introduction

If a transparent vessel partially filled with water is vibrated in the vertical direction, complicated phenomena can be observed. If the vibration is sufficiently strong, small individual gas bubbles created by surface disturbances appear in the lower part of the vessel.[3] These bubbles do not rise to the surface but move along the bottom or side, or perform vibratory motions in the middle of the vessel. It is the purpose of this paper to contribute to the understanding of the complex phenomena observed by presenting an analysis for the motion of a gas bubble in a vibrated vessel.

To demonstrate the fact that gas bubbles in a vibrated tank may not rise to the surface as one would expect from considerations of buoyancy, the following simple experiment was made. A rubber-skinned test bubble of about $^1/_4$-in. diam was attached to a short piece of string at the end of a wire; this balloon was inserted in a cylindrical transparent plastic test tank, Fig. 1, placing it on the centerline of the tank about 2 in. above the bottom. Without vibration the bubble rises stretching the string vertically. Vibrating the tank vertically with gradually increasing acceleration, the position of the bubble on the centerline became unstable and snapped into a deflected position I, see Fig. 2. A slight

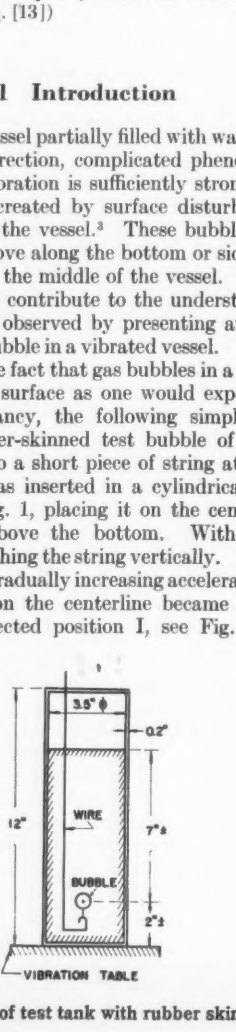

Fig. 1 Dimensions of test tank with rubber skinned bubble

Received May 12, 1956.

[1] The investigation on which this paper is based was sponsored by The Ramo-Wooldridge Corp., Los Angeles, Calif.

[2] Director. Mem. ARS.

[3] This fact was first observed by Y. C. Lee, Principal Engineer, and C. C. Miesse, Physicist, Aerojet-General Corp., who brought the matter to the writer's attention.

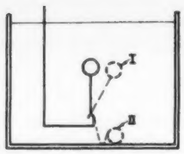

Fig. 2 Positions of test bubble

further increase of the acceleration made this position also unstable, and the bubble went into position II at the bottom of the tank. If the acceleration was decreased by about $1g$, the bubble returned to its original position. The acceleration required to make the bubble sink was somewhat frequency dependent, as may be seen from Table 1 giving the acceleration required to hold the bubble in position II, Fig. 2.

Table 1 Critical accelerations

Cycles/sec	60	90	120	150	175	200
Acceleration	$16g$	$14.5g$	$14g$	$13g$	$12g$	$11.5g$

The unexpected sinking of bubbles—contrary to buoyancy—has its counterpart in the field of underwater explosions. It is known from extensive work on this subject that pulsating explosion bubbles do not simply rise but move in a modified manner known as "bubble migration." Due to migration, an explosion bubble may in certain cases sink, instead of rise. It can therefore be expected that an analysis using methods similar to those employed in the explosion field will give an understanding of the phenomena observed.

In the case under consideration the vibration will excite pulsations (meaning changes in diameter) of the bubble and it will be shown that migration effects do occur which modify the path of the bubble and may even cause it to sink. Specific attention will be given to the case of a bubble moving vertically in an oscillatory manner, a situation which separates the cases of rising and sinking bubbles.

The migration phenomena of explosion bubbles can be explained by an analysis using an incompressible, inviscid fluid (Herring (1),[4] Taylor (2), and Bryant (3)), except that such an analysis does not explain the decay of the bubble pulsations due to radiation. As this decay affects the migration of the explosion bubble only in a secondary manner, it is usually considered as a correction. In the present problem it is intended to obtain the response of the bubble for cases where the amplitude of the pulsation is much smaller than in the explosion case, and radiation effects need therefore not be included at all. It is also assumed that the frequency of the forced oscillations of the vessel is small versus the natural frequency of the bubble; this excludes the possibility of resonance of the bubble pulsations, which would have required compressibility as a damping mechanism. The present analysis, similar to the references quoted, does not consider changes in the spherical shape of the bubble. The assumption of spherical bubbles is confirmed by observation of explosion bubbles, except in their most contracted stage. As only relatively small pulsations will occur in the present case any deviations from spherical shape can be expected to be minor and unimportant. This reasoning is supported by the fact that no visibly nonspherical bubbles were observed in the tests.

The migration of bubbles is a second-order effect which cannot be explained by a linear theory of small vibrations. It is therefore necessary to obtain equations of motion for large displacements which, even for an approximate analysis, can not be completely linearized.

To reduce the problem to its simplest form the behavior of a bubble in a large rigid vessel is considered first, Section 2. It is assumed that the bubble is sufficiently far away from any surface—at least several bubble diameters—such that interactions with the surface may be neglected. The results obtained are generalized in Section 3 to allow for the quite important effect of the elasticity of the vessel, and—qualitatively—for the effect of proximity of surfaces and of viscosity.

[4] Numbers in parentheses indicate References at end of paper.

2 Behavior of a Gas Bubble in a Large Rigid Vessel

It is intended to study the motion of a small spherical gas bubble in an incompressible, inviscid fluid if the vessel containing the fluid is vibrated in the vertical direction. It is assumed in this section that the vessel is rigid and that a constant ullage pressure p_0 will be maintained above the surface of the fluid; it is further assumed that the bubble is sufficiently far away from any surface—at least several diameters—such that interactions are negligible.

Equations of Motion

Excluding rotational motions of the fluid, the state of the system shown in Fig. 3 is fully described by three generalized coordinates

$x(t)$ = vertical position of vessel with respect to a reference line

$\Delta(t)$ = increase of bubble radius above a reference radius a

$z(t)$ = relative depth of bubble below the moving surface; $\dot{z}(t)$ is therefore the relative velocity of the bubble with respect to the fluid

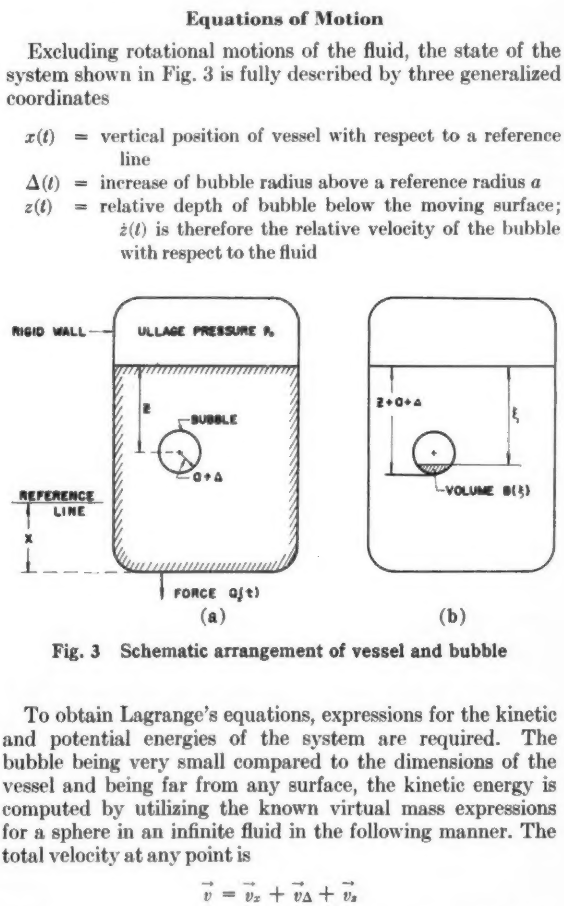

Fig. 3 Schematic arrangement of vessel and bubble

To obtain Lagrange's equations, expressions for the kinetic and potential energies of the system are required. The bubble being very small compared to the dimensions of the vessel and being far from any surface, the kinetic energy is computed by utilizing the known virtual mass expressions for a sphere in an infinite fluid in the following manner. The total velocity at any point is

$$\vec{v} = \vec{v}_x + \vec{v}_\Delta + \vec{v}_z$$

where $\vec{v}_x = \dot{x}$ is the vertical velocity of the vessel which is not a function of the location, and $\vec{v}_\Delta$ and $\vec{v}_z$ are the velocities due to the coordinates Δ and z. Let dV be the element of volume, ρ the density of the fluid; the kinetic energy T is

$$T = \frac{\rho}{2}\int \vec{v}^2\, dV = \frac{\rho}{2}\dot{x}^2\int dV + \frac{\rho}{2}\int \vec{v}_\Delta^{\,2}\, dV + \frac{\rho}{2}\int \vec{v}_z^{\,2}\, dV + \rho\dot{x}\int (u_\Delta + u_z)dV \ldots [1]$$

where u_Δ and u_z are the vertical components of $\vec{v}_\Delta$ and $\vec{v}_z$, re-

spectively. There is no coupling term between $\vec{v}_\Delta$ and $\vec{v}_z$ because of symmetry. The value of the first term in [1] is simply $M\dot{x}^2/2$ where M is the total mass of the fluid in the vessel; the second and third terms are the familiar expressions for the kinetic energies of the respective motions of a sphere of radius $a + \Delta$ (see (4) pp. 122, 124), while the last term, a coupling term, is evaluated in Appendix 1. The total kinetic energy is, therefore

$$T = \frac{M}{2}\dot{x}^2 + 2\pi\rho(a + \Delta)^3\dot{\Delta}^2 + \frac{\pi}{3}\rho(a + \Delta)^3\dot{z}^2 - \frac{4\pi}{3}\rho\dot{x}\frac{\partial}{\partial t}[(a + \Delta)^3 z] \quad \ldots [2]$$

The potential energy consists of three parts: the potential of the gravity field, $-gMx + g\rho\cdot(4\pi/3)\ (a + \Delta)^3 z$; the potential of the gas above the surface, $(4\pi/3)\ (a + \Delta)^3\ p_0$; the potential of the gas inside the bubble, which can be computed from the pressure-volume relation

$$p(a + \Delta)^{3\gamma} = p_1\, a^{3\gamma} \quad \ldots\ldots [3]$$

where γ is the ratio of the specific heats, and p_1 the pressure in the bubble when its size equals the reference radius a. The potential becomes

$$\int_v^\infty p dv = \frac{4\pi}{3}\frac{p_1}{\gamma - 1}\frac{a^{3\gamma}}{(a + \Delta)^{3\gamma - 3}} \quad \ldots\ldots [4]$$

Collecting all terms

$$P = -gMx + \frac{4\pi}{3}(a + \Delta)^3(p_0 + g\rho z) + \frac{4\pi}{3(\gamma - 1)}\frac{p_1 a^{3\gamma}}{(a + \Delta)^{3\gamma - 3}} \quad \ldots [5]$$

The general form of Lagrange's equation is

$$\frac{\partial}{\partial t}\frac{\partial L}{\partial \dot{q}_n} - \frac{\partial L}{\partial q_n} = Q_n \quad \ldots\ldots [6]$$

where $L = T - P$; the coordinates q_n are in turn Δ, z and x, while Q_n are the respective generalized forces. In the present case all forces have been included in the potential P except the external driving force producing the oscillation. As this force does no work if Δ and z change, we have $Q_\Delta = Q_z = 0$, while Q_x does not vanish. If one visualizes a situation where the displacement x is prescribed, Equation [6] with respect to the coordinate x is not required because it serves only to determine the force Q_x; this leaves two differential equations for the two unknown functions Δ and z

$$\frac{\partial}{\partial t}\frac{\partial L}{\partial \dot{\Delta}} - \frac{\partial L}{\partial \Delta} = 0 \qquad \frac{\partial}{\partial t}\frac{\partial L}{\partial \dot{z}} - \frac{\partial L}{\partial z} = 0$$

After substitution

$$\frac{\partial}{\partial t}[(a + \Delta)^3\dot{z}] = 2(a + \Delta)^3(\ddot{x} - g) \quad \ldots\ldots [7]$$

$$\ddot{\Delta} + \frac{3\dot{\Delta}^2}{2(a + \Delta)} - \frac{p_1 a^{3\gamma}}{\rho(a + \Delta)^{3\gamma+1}} + \frac{(g - \ddot{x})z}{a + \Delta} - \frac{\dot{z}^2}{4(a + \Delta)} = -\frac{p_0}{\rho(a + \Delta)} \quad \ldots [8]$$

Discussion of Equation [7]

This equation represents the principle of conservation of momentum and it is useful to consider it for the simple case when the vessel is at rest, $\ddot{x} = 0$. Using the bubble volume $v = (4\pi/3)\ (a + \Delta)^3$ as variable, [7] may be written

$$\frac{\partial}{\partial t}\left(\frac{\rho}{2}v\dot{z}\right) = -\rho g v \quad \ldots\ldots [7a]$$

where the term $(\rho/2)v$ is the virtual mass of the bubble (for the z motion) while $-\rho g v$ is the buoyancy. If v changes with time, the velocity $\dot{z}$ is

$$\dot{z} = -2g\frac{1}{v}\int_{t_0}^t v\, dt$$

Due to the fact that the bubble volume v is necessarily positive, the integral will always increase with t; the term $1/v$ will increase the velocity $\dot{z}$ if v is smaller or decrease it if v is larger than average, but $\dot{z}$ will always remain negative and the bubble will rise continuously.

Now consider the situation if a time dependent acceleration $\ddot{x}(t) = Ng\cos\omega t$ is imposed where N is a number. Equation [7] becomes

$$\dot{z} = -2g\frac{1}{v}\int_{t_0}^t [v - vN\cos\omega t]dt \quad \ldots\ldots [9]$$

It is immediately apparent that the integral will not continuously increase if $N > 1$. To show that the integral can even become negative, i.e., that the bubble can sink, let the bubble execute an imposed periodic pulsation $v = v_0\ (1 + \alpha\cos\omega t)$ where α is number defining the magnitude of the pulsations. By substitution

$$\int_{t_0}^t (v - vN\cos\omega t)dt = v_0\int_{t_0}^t\left[1 - \frac{\alpha N}{2} + (\alpha - N)\cos\omega t - \frac{\alpha N}{2}\cos 2\omega t\right]dt \quad \ldots [10]$$

The terms $\cos\omega t$ and $\cos 2\omega t$ under the integral give oscillatory contributions, while the first two terms give a monotone contribution which describes the direction of the over-all motion. If $\alpha N > 2$ the integral will ultimately be negative and the bubble will sink;[5] if $N\alpha = 2$ the bubble will execute an oscillation about a mean position.

The above consideration shows the possibility of bubbles sinking, provided the bubble volume changes in the prescribed manner. It remains to be shown that the imposed vibration will produce the assumed or an equivalent pulsation. This requires simultaneous consideration of the two Lagrangian equations, [7] and [8].

Oscillation of a Bubble Around a Mean Position

Restricting the general problem of the motion of the bubble, it is asked whether there are combinations of imposed acceleration $\ddot{x} = Ng\cos\omega t$ and bubble size and location for which a bubble will undergo a *periodic* vertical motion and pulsation. The previous discussion showed that for large N (say $N \sim 10$) only small volume changes $\alpha = 2/N$ are required; the equations can therefore be linearized with respect to the change of radius Δ.

It is convenient to replace the coordinate z by $z = h + \xi$ where h is the depth at which a bubble of the reference radius

[5] The above derivation being based on energy concepts, an additional physical understanding of the phenomena can be gained by a consideration in terms of forces acting on the bubble. Using the concept of the "virtual mass" of the fluid moving with the bubble, its motion can be found from the condition that the change of momentum $(\partial/\partial t)\cdot(\rho v\dot{z}/2)$ must equal the applied force (where $\rho v/2$ is the virtual mass; compare the third term of [2]). In case the vessel is not vibrated the only force is the buoyancy of the bubble, $-\rho g v$, resulting in [7a]. In the more general case when the vessel is accelerated upward or downward, the force can be obtained by increasing or decreasing, respectively, the value of g in the buoyancy term; this is, however, not the only effect on this term. During the upward acceleration the pressure in the location of the bubble will be larger, and the average value of the volume v will therefore be smaller than during the downward acceleration. If the vessel is accelerated alternatively up and down in a symmetric pattern (gravity being absent), the volume change will result in an excess of downward momentum during each period. If gravity is also present, the downward momentum gained from the vibration will combine and may exceed the upward one due to static buoyancy, leading to the sinking of bubbles.

a would be in equilibrium if prevented from rising; this gives the relation $p_1 = p_0 + hg\rho$. Equations [7, 8] can then be arranged

$$\frac{\partial}{\partial t}[(a + \Delta)^3 \dot{\xi}] = 2(a + \Delta)^3(\ddot{x} - g) \qquad [11]$$

$$\ddot{\Delta} + \frac{3}{2}\frac{\dot{\Delta}^2}{a + \Delta} + \frac{p_1}{\rho(a + \Delta)}\left[1 - \left(\frac{a}{a + \Delta}\right)^{3\gamma}\right] + \frac{1}{a + \Delta}(g - \ddot{x})\xi - \frac{\dot{\xi}^2}{4(a + \Delta)} = \frac{h}{a + \Delta}\ddot{x} \qquad [12]$$

If Δ is small, the second term of [12] can be dropped and the third term becomes by expansion in powers of Δ

$$\frac{3\gamma p_1}{a^2\rho}\Delta \equiv \Omega^2 \Delta \qquad [13]$$

where Ω is the frequency of small oscillation of a bubble of radius a at the pressure p_1 (1, p. 79). If the terms containing ξ and $\dot{\xi}^2$ in [12] could also be neglected, which will be seen to be permissible later, Equations [11, 12] become

$$\frac{\partial}{\partial t}[(a + 3\Delta)\dot{\xi}] = 2(a + 3\Delta)(\ddot{x} - g) \qquad [14]$$

$$\ddot{\Delta} + \Omega^2 \Delta = \frac{h}{a}\ddot{x} \qquad [15]$$

If $\ddot{x} = Ng \cos \omega t$, the second equation has a solution of the form

$$\Delta = \frac{\alpha}{3} a \cos \omega t \qquad [16]$$

where

$$\alpha = \frac{3h}{a^2} Ng \frac{1}{\Omega^2 - \omega^2} = \frac{h\rho}{\gamma p_1} Ng \frac{1}{1 - \omega^2/\Omega^2} \qquad [17]$$

Substitution of [16] into [14] gives

$$\frac{\partial}{\partial t}[(1 + \alpha \cos \omega t)\dot{\xi}] = 2(1 + \alpha \cos \omega t)(Ng \cos \omega t - g) =$$
$$(\alpha N - 2)g + 2Ng \cos \omega t + \alpha Ng \cos 2\omega t - 2\alpha g \cos \omega t \qquad [18]$$

which leads to an oscillatory solution only if $\alpha N = 2$. In this case

$$\dot{\xi} = \frac{Ng}{\omega}\left(2 \sin \omega t - \frac{3\alpha}{2}\sin 2\omega t \ldots\right) \qquad [19]$$

where terms containing higher powers of α were omitted. Further

$$\xi = -\frac{Ng}{\omega^2}\left(2 \cos \omega t - \frac{3\alpha}{4}\cos 2\omega t \ldots\right) \qquad [20]$$

The oscillatory solution visualized can only have physical meaning if the amplitude ξ of the vertical motion remains smaller than the depth h, as the bubble would otherwise vent; this requires

$$\omega^2 \gg Ng/h \qquad [21]$$

To justify the dropping of the terms containing ξ when obtaining [15], the neglected terms can be estimated for $N \gg 1 \gg \alpha$

$$\frac{1}{a + \Delta}\left[(g - \ddot{x})\xi - \frac{1}{4}\dot{\xi}^2\right] \sim \frac{N^2g^2}{4a\omega^2}(1 + 3\cos 2\omega t) = O\left(\frac{N^2g^2}{a\omega^2}\right) \qquad [22]$$

This can be compared with the right-hand side of [12] which is of the order

$$\frac{h}{a + \Delta}\ddot{x} = O\left(\frac{hNg}{a}\right) \qquad [23]$$

It is easily seen that the necessary condition [21] automatically ensures that the expression [22] is small versus [23]. The neglected terms can therefore never be of consequence for the oscillatory solutions contemplated.

Equations [17, 18] can be solved for the value h, noting $p_1 = p_0 + \rho g h$

$$h = \frac{p_0}{\rho g}\frac{1}{\dfrac{N^2\Omega^2}{2\gamma(\Omega^2 - \omega^2)} - 1} \qquad [24]$$

the solution being meaningful only if [21] is satisfied. The size of the bubble appears only in the value of the frequency Ω; and, because for small bubbles usually $\Omega^2 \gg \omega^2$, Equation [24] simplifies to

$$h = \frac{p_0}{\rho g}\frac{2\gamma}{N^2 - 2\gamma} \qquad [25]$$

Equation [25] furnishes positive values h for any value $N > \sqrt{2\gamma}$, but because $\alpha = 2/N$ was assumed to be small, h may be inaccurate unless N is much larger than $\sqrt{2\gamma}$. Equation [21] then defines frequencies ω^2 above which the depth found will apply. If ω is comparable to Ω, Equation [24] must be used; however, the form of this equation is such that h becomes negative if $\omega > \Omega$, and no oscillatory solution exists if $\omega > \Omega$; as a rule ω must even be noticeably smaller than Ω, otherwise [21] will not be satisfied.

Stability of the Oscillatory Solution

It is important to realize that the oscillatory solution just obtained is unstable; i.e., one cannot expect to observe bubbles executing oscillations on the level h given by [24, 25]. To prove the instability, consider [17]. If h is slightly smaller than the required critical value, α will also be smaller than required to satisfy the condition $\alpha N = 2$; the first term of [18] will then be negative such that the bubble will have an average upward velocity; i.e., it will move away from the level h of steady oscillations. If h is slightly larger, the bubble will similarly have an average downward velocity, again away from the level h. In case of any disturbance, regardless in which direction, the bubble will not return to its original motion; i.e., the motion is unstable.

In spite of the fact that the motion described by the solution found has therefore no physical reality, the critical level h for the unstable solution has an important meaning: *bubbles above the critical level h will rise to the surface, while those below will sink.* This conclusion is in qualitative agreement with observations.

It will be seen in Section 3 that the assumption of a rigid vessel on which the above discussion is based is an oversimplification, and a more refined analysis may furnish more than one level of oscillatory solutions, some of which are stable.

Comparison with the Pilot Tests

The result obtained, Equations [24, 25], can be compared with the result of the simple test reported in Table 1. To obtain a fair comparison the effect of the weight of the rubber skin should be allowed for, and it can be seen easily that the added weight will *reduce* the critical depth h.[6] One should expect therefore that the values h computed from [24] for the appropriate values N of the acceleration should be larger than the test depth of the bubble $h \simeq 7$ in. The natural frequency Ω of the $^1/_4$-in. bubble tested is so much higher ($\Omega > 1000$ cps) than the test frequencies ω that [25] may be used; the computed values of h are shown in Table 2, using $p_0/\rho g = 33$ ft and $\gamma = 1.4$.

[6] The depth h will be reduced to $h(1 - \beta)$ where β is the ratio of the weight of the skin to the buoyancy of the bubble. The ratio β for the test case is not known but was about 0.1–0.2.

Table 2 Computed values of h

(h, in.; $\dot{\xi}$, ips)

Cycles per sec	60	90	120	150	175	200
From Table 1						
$N =$	16	14.5	14	13	12	11.5
From Eq. [24]						
$h =$	4.4	5.4	5.8	6.7	7.9	8.7
$\dot{\xi} \simeq 2Ng/\omega =$	32	20	14	11	8.5	7

While the computed values h are of the expected order of magnitude, not all are larger than $h = 7$ in. as predicted by the theory. It appears that the lack of agreement can be ascribed to the unrealistic assumption of an inviscid fluid, which is not justified for the entire range of the test. To show this, the last line of Table 2 contains the maximum velocities $\dot{\xi}$ of the bubble, computed from the first term of [19], $\dot{\xi} \simeq 2Ng/\omega$. The problem of viscosity effects is discussed in Appendix 2, where it is concluded that such effects are small provided the velocity of the bubble remains small compared to its terminal velocity when rising in a gravity field; for the present case this velocity is of the order of 10 ips, and the inviscid analysis cannot be expected to give a good value for the depth h, except for high frequencies $\omega >$ 150 cps. It is also concluded in the Appendix that viscosity will increase the value of the critical depth h; in the limiting case the actual depth would be three times the value according to [24, 25]. The actual depth $h = 7$ in. being larger than the computed ones shown in Table 2, the direction of the differences is in accordance with this prediction.[7]

3 Motion of a Gas Bubble in an Elastic Vessel

Equations of Motion

Maintaining all other assumptions made in the previous section, the effect of the elasticity of the vessel on a small bubble can only originate from the modified pressure field in the elastic vessel. In the rigid vessel the pressure at any instant is only a linear function of the depth below the surface, while in an elastic vessel the pressure is a nonlinear function of all three coordinates.

It is not necessary to treat the problem of the vessel and bubble as a unit. Let the pressure field in the vibrated elastic vessel without the bubble be known; due to the fact that the motion of a small bubble can essentially only depend on the pressure field in its immediate vicinity, one can use the equations of motion derived for the case of a rigid vessel for any case, provided one identifies the significant factors, i.e., the pressure $\bar{p}$ due to the vibration and its gradient. For the present purpose it is sufficient to use the simplified Equations [14, 15]; $\bar{p}$ due to the vibration for the case of a rigid vessel is

$$\bar{p} = -\rho h\ddot{x} \qquad \text{grad } \bar{p} = \partial\bar{p}/\partial h = -\rho\ddot{x} \quad [26]$$

[7] In a private communication, S. A. Zwick, Aerojet-General Corp., has pointed out that the assumption of the isentropic law for the bubble behavior, Equation [3], is not strictly correct. According to the communication it can be shown that in the case of harmonious oscillations the exponent γ in [3] should be replaced by a number $\bar{\gamma}$, which depends on an appropriate nondimensional parameter and is limited, $1 < \bar{\gamma} < \gamma$, the lower limit describing isothermal behavior. Accepting this comment, the analysis presented here remains valid if γ in the results is replaced by $\bar{\gamma}$. It is pertinent to check if the matter might explain the difference between the observed and computed values h shown in Table 2. It is easily seen, however, that this is not the case; values $\bar{\gamma} < \gamma$ lead to a reduction of the values h in Table 2 which is a correction in the wrong direction. While this correction is bound to exist, the conclusion that viscosity effects are the major cause for the differences still holds.

and the equations of motion can be rewritten

$$\ddot{\Delta} + \Omega^2\Delta = -\bar{p}/a\rho \quad [27]$$

$$\frac{\partial}{\partial t}[(a + 3\Delta)\dot{\xi}] = -2(a + 3\Delta)\left(\frac{1}{\rho}\frac{\partial \bar{p}}{\partial h} + g\right) \quad [28]$$

where $\dot{\xi}$ is the vertical component of the bubble velocity. Similar equations for the horizontal velocities can be written but do not contain the term g.

Oscillatory Solutions

Consider the case where the imposed pressure is of the form

$$\bar{p} = \rho g f(h) \cos \omega t \quad [29]$$

where $f(h)$ is positive, has the dimension of a length, and is a function of the depth h and also of horizontal coordinates. Searching for oscillatory solutions, [27, 29] give

$$\Delta = \frac{\alpha}{3} a \cos \omega t \quad [30]$$

where

$$\alpha = -\frac{g\rho}{\gamma p_1}\frac{f(h)}{1 - \omega^2/\Omega^2} \quad [31]$$

Substitution in [5] gives

$$\frac{\partial}{\partial t}[(a + 3\Delta)\dot{\xi}] = -ag[2 + \alpha f'(h) + \text{oscillatory terms}] \quad [32]$$

where $f'(h) = \partial f/\partial h$. The right-hand side is purely oscillatory only if $2 + \alpha f' = 0$, or

$$\frac{f'f}{p_1} = \frac{2\gamma}{\rho g}(1 - \omega^2/\Omega^2) \quad [33]$$

which can be solved for the depths h of oscillatory solutions.

Stability of Oscillatory Solutions

To decide on the stability of such solutions, consider the situation at a depth $h + dh$ which differs slightly from a root of [33]. In such a case

$$\frac{\partial}{\partial t}[(a + 3\Delta)\dot{\xi}] = \left[-ag\frac{\partial}{\partial h}(2 + \alpha f')\right]dh + \text{oscillatory terms} \quad [34]$$

If the coefficient of dh in this expression is positive the bubble will migrate away from the oscillation level h and the solution is unstable; but if the coefficient is negative the disturbed bubble will return to the original state and the solution is stable. The condition for stability after substitution is

$$\frac{\partial}{\partial h}\left(\frac{ff'}{p_1}\right) < 0 \quad [35]$$

Noting $p_1 = p_0 + g\rho h$, the condition may be written

$$ff'' < -f'^2 + \frac{\rho g}{p_1}f'f \quad [36]$$

In the case of a rigid vessel, $f(h) = Nh$, and stability would require

$$0 < -1 + \frac{\rho g h}{p_1}$$

which can never be satisfied because $p_1 > \rho g h$.

Similarly, one can investigate stability against disturbance in the horizontal plane, say in a direction r. The equation for the migration follows from [28] by setting $g = 0$ and replacing h by r. Oscillatory solution can only occur if

$$\partial f/\partial r = 0 \quad [37]$$

The condition for their stability becomes

$$f\frac{\partial^2 f}{\partial r^2} < 0 \qquad [38]$$

With f positive, these two equations will be satisfied at points on any level h where f is a maximum. As the imposed vibration pressure is proportional to f it follows that the bubble will oscillate in a stable motion if *Equation [36] is satisfied* and if the *pressure amplitude* is *a maximum* compared to other points on the same level h.

It must also be stressed that in locations where the oscillations are stable, bubbles *above* the level h will *sink* and those *below* will *rise*. This is the exact opposite of what was found in the case of a rigid vessel, where the only possible oscillatory motion was unstable.

Application to a Cylindrical Tank

The pressure field p for the case of an elastic cylindrical tank, Fig. 4, has been studied in (5). In the range of frequencies of present interest, the pressure distribution is very well approximated by an expression[8]

$$f(h) = \bar{C}\frac{R}{\mu}\sin(\mu\, h/R)I_0(\mu\, r/R) \qquad [39]$$

where $\bar{C}$ and μ are constants, r is the radial coordinate, R the tank radius, and I_0 denotes the modified Bessel function.

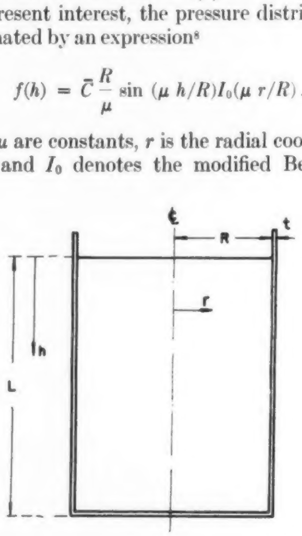

Fig. 4 Dimensions of elastic cylindrical tank

The constant $\bar{C}$ defines the magnitude of the pressure, while μ is defined in (5); it depends on the properties of the tank[9] and on the forcing frequency ω.

The depth h of oscillatory solutions can now be determined from [33] which becomes

$$\frac{\sin(2\mu\, h/R)}{(2\mu p_0/R\rho g) + 2\mu h/R} = \frac{2\gamma}{C^2}(1 - \omega^2/\Omega^2) \qquad [40]$$

where

$$C = \bar{C}\, I_0(\mu\, r/R) \qquad [41]$$

Equation [40] is graphically represented in Fig. 5 in a typical manner. If the constant C, representing the applied acceleration, is large enough there will be two roots $2\mu\cdot(h/R) < \pi$ (or one double one), and possibly further ones above 2π. To determine the stability, [36] could be used. However, Equation [35] from which [36] was derived is identical with the statement that the derivative of the left side of [40] be negative; as the slope of this curve in Fig. 5 for the first root

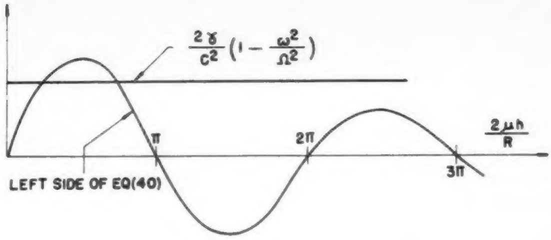

Fig. 5 Graphic representation of Eq. [40]

is necessarily positive, it will be unstable, while the next larger root where the slope is negative is stable. The third root, if any, will again be unstable, etc. The roots occur in pairs of one unstable and one stable one; if a double root occurs it is easily seen that it is unstable.

The question of the location of a point of stable oscillation in the horizontal plane remains to be considered. According to [38] it is necessary that the pressure function f be a maximum considered as function of r; the modified Bessel function $I_0(\mu\, r/R)$ in [39] has a minimum for $r = 0$, but no maximum at all, indicating that there are no locations of stable oscillations in the interior of the tank. The reasoning leading to the stability criterion [35] indicates that bubbles will move away from points of unstable oscillations; applied to the present case, they will therefore move away from the axis of the tank toward the walls. In the vicinity of the walls the present theory ceases to be valid, and to obtain a complete picture the effect of surfaces must be included, at least in a qualitative manner.

Effect of Surfaces on the Motion of Bubbles

The effect of a neighboring rigid surface on the motion of an oscillating bubble has been determined by the use of the image principle in (1). The major effect found is an attraction of the bubble by the field of the image. In first approximation the bubble obtains an additional velocity $\dot{\xi}_M$ directed toward the rigid surface

$$\dot{\xi}_M = -\frac{3}{4H^2}\bar{a}^2\frac{d\bar{a}}{dt} + \frac{3}{2H^2\bar{a}^3}\int_0^t \bar{a}^4\left(\frac{d\bar{a}}{dt}\right)^2 dt \qquad [42]$$

where H is the distance of the center of the bubble from the surface, and $\bar{a} = a + \Delta$ the instantaneous radius of the bubble. If the radius $\bar{a}$ varies harmonically the first term is just oscillatory and therefore not important, while the second one is the continuing migration *toward* the surface.

While [42] was derived for a rigid surface, it should apply approximately also to the case of the walls of an elastic vessel provided the bubble is sufficiently small. This conclusion will hold provided that the mass of the wall area affected by the pressure field[10] of the bubble is appreciably larger than the virtual mass of the bubble.

It is therefore concluded that small bubbles will be subject to an additional motion toward the walls of the vessel which is superimposed on the motion previously determined. This additional motion is proportional to $1/H^2$ and is therefore appreciable only if the distance H is of the order of the radius a.

Discussion of the Result for an Elastic Cylindrical Tank

Equation [40] can be used to determine the regions of different bubble behavior in an elastic cylindrical tank. For a given frequency and externally imposed acceleration of the tank, the constants $\bar{C}$ and μ in [39] are computed according to (5). Solutions h of [40], if any, will also be functions of the location r; these solutions will define surfaces separating regions of different bubble behavior.

Fig. 5, representing [40] in a typical manner, indicates that for small values of C, i.e., for small accelerations, no

[8] According to (5) this expression is a good approximation except in a region near the bottom of the tank where $h > L - R/2$.

[9] For the special case of a rigid tank one finds $\mu = 0$, and [39] becomes in the limit $f(h) = \bar{C}h$. Substitution in [29] shows that in this case $\bar{C} = N$, where Ng is the peak acceleration applied to the rigid tank.

[10] The order of magnitude of this area is H^2.

solution h exists. Noting that $C = \bar{C}\, I_0(\mu\, r/R)$ is also a function of the radius, it is seen that the value C is a minimum for $r = 0$ and increases toward the walls, $r \rightarrow R$. Therefore, if the acceleration is gradually increased a range will be reached where [40], while having no root for $r = 0$, does have solutions for larger values of r. The resulting situation is shown in Fig. 6(a). For a somewhat larger acceleration, [40] will have roots for any value of r, and two separate surfaces as shown in Fig. 6(b) are obtained.

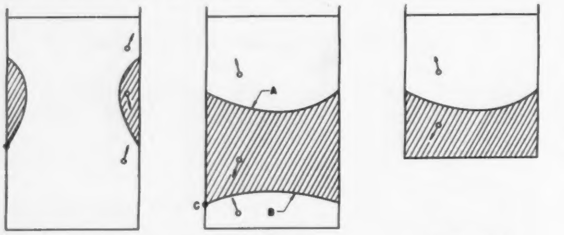

Fig. 6(a) Fig. 6(b) Fig. 6(c)

The behavior in the regions separated by these surfaces can be best described by an indication of the direction of the vertical component of the motion in the various regions. As previously indicated there will also be horizontal motions—from the centerline toward the walls—in all regions. As the upper surface A, Fig. 6(b), represents locations of "unstable" oscillations, bubbles will move away from it; the reverse applies to the lower surface B. It follows that bubbles in the shaded volume between the two surfaces will move downward and outward, while the motion elsewhere will be upward and outward. In the vicinity of the walls of the vessel the outward velocity will be increased by the additional local motion toward the wall. Bubbles below the upper surface A can be expected to find their way toward C, where the lower surface B meets the wall of the tank.

In the transition case shown in Fig. 6(a) bubbles in the shaded region will again move downward toward C, while those in the lower part of the tank may go toward C or vent, depending on their radial location.

One further case which should be mentioned is shown in Fig. 6(c). It is possible that the lower surface B defined by the second root of [40] lies outside the tank. In this case bubbles will simply move down toward the bottom and remain there. They will not move toward the wall because the pressure distribution [39], from which the outward motion elsewhere is derived, does not apply close to the bottom. The situation shown in Fig. 6(c) is typical for a rather rigid tank where the parameter μ is quite small; it applies for the pilot tests described in the Introduction.

In very flexible tanks more than two separating surfaces may occur as shown in Fig. 7. In such cases two or more circles C, C_1 are potential locations for the collection of bubbles.

As the analysis presented considers only the motion of isolated bubbles, it is proper to ask if the conclusion that bubbles

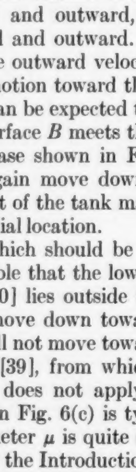

Fig. 7

will remain near certain points C is valid if many bubbles are close to each other, such that interactions must be expected. This point has been studied in (7); it was found that with certain limitations clusters of closely spaced bubbles have stable positions from which they will not rise in close proximity to the points C to which bubbles migrate. It has further been observed in the tests, and can be shown analytically, that clusters strongly attract isolated bubbles. While the analysis only applies to the initial stage, it appears from the additional study (7) that the interaction of bubbles does not counteract the formation of clusters.

4 Summary

An understanding has been obtained of the mechanism governing the motion (migration) of small gas bubbles in vibrated vessels described in the introduction. Differential equations describing the behavior were derived, [27, 28], under the restrictive assumption of an inviscid fluid; from qualitative considerations it was concluded that viscosity does not affect the mechanism of migration, but may have quantitative effects. A criterion when the influence of viscosity will be appreciable is given. The situation is discussed at the end of Section 2 when the results of the analysis are compared with the pilot tests.

No attempt has been made to solve the nonlinear differential equations in general. Instead, locations in space were determined in which the differential equations have time periodic solutions, representing small oscillations of the bubbles. The loci of these solutions form surfaces which separate the tank into regions of different bubble behavior. In the case of a rigid tank it was found that the bubbles above a certain level h will rise toward the surface, while those below will sink to the bottom. In the case of elastic vessels the regions have complicated shapes, discussed for cylindrical tanks in Section 3 and shown in Figs. 6 and 7. From the character of the regions it is concluded that, if many bubbles are present, clusters of bubbles will collect in certain locations near the wall or bottom.

The results obtained do not yet give a complete explanation of the observations of the test tank. In the tests at certain accelerations large numbers of bubbles streamed from the surface to lower regions of the tank; it appeared to the eye that the bubbles forming at the surface started with an initial velocity downward which enabled them to travel down and reach the region (say below surface A, Figs. 6(b), 6(c)) of sinking bubbles. These large initial downward velocities of bubbles were observed only at a time when the surface of the fluid executed very pronounced sloshing motions, which occurred regularly at large accelerations and seemed also to be caused by the longitudinal vibrations. Further work on the origin of the sloshing motion and its effect on bubbles near the surface is therefore required for a complete understanding of the observations.[11]

APPENDIX 1

Evaluation of the Last Integral in Equation [1]

Let $dV = d\xi\, dA$ where ξ is a vertical coordinate, Fig. 3(b), and dA is an element of area in the horizontal plane

$$\iiint (u_\Delta + u_s)dV = \int\left[\iint (u_\Delta + u_s)dA\right]d\xi \ldots\ldots [a]$$

(Continued on page 978)

[11] AUTHOR'S NOTE: After submission of this paper the author's attention has been drawn to the fact that migration of small bubbles has been discussed in ONR Report (Project NR-384-903): "Gaseous-Type Cavitation in Liquids," by M. D. Rosenberg, Acoustics Research Lab., Harvard University. Migration of very small bubbles in an ultrasonic field is described (pp. 40-44) and qualitatively explained in a manner similar to the physical consideration in Footnote 5 of this paper. The report also mentions observation of stable and unstable locations for bubbles which are the equivalent of those discussed in Section 3 for elastic vessels.

A Solid-Liquid Rocket Propellant System

GEORGE E. MOORE[1] and KURT BERMAN[2]

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A self-igniting hybrid rocket propellant system employing 90 per cent hydrogen peroxide as the oxidizer and polyethylene as the fuel is described. The reasoning which led to this choice and the advantages achieved are outlined. Some results obtained in tests with one type of fuel charge are given with some qualitative discussion on the operation.

Nomenclature

A_p = cross-sectional area for gas passage along the fuel charge
A_t = nozzle throat cross-sectional area
b = linear burning rate
C^* = characteristic velocity $gP_cA_t/\dot{w}$
G = mass flow per unit cross-sectional area
I_{sp} = specific impulse lb-sec/lb
p_c = chamber pressure
R_w = reactant ratio $= \dfrac{\text{oxidizer flow rate}}{\text{fuel flow rate}}$
$\dot{w}$ = propellant flow rate

Introduction

SEVERAL years ago, an investigation of a hybrid (solid-liquid propellant) rocket propellant system was conducted by the General Electric Company as part of an Army Ordnance Contract. The system studied involves the use of 90 per cent hydrogen peroxide, the oxidizer, in combination with a solid fuel, generally polyethylene. The purpose of this report is to review the reasoning which led initially to the interest in such a system and to the choice of the particular materials used; in addition, some of the results will be briefly discussed.

The advantages to be gained from systems of this kind are not immediately obvious; in fact, there are probably not many solid-liquid propellant combinations which do offer any advantages without introducing other difficult problems. The following summary of the desirable characteristics of the system described here will show why it appeared to be interesting after some rocket engine tests:

1 The theoretical specific impulse is good, with a maximum value of 228 lb-sec/lb at 300 psi and oxidizer/fuel weight ratio of about 6.

2 The average density is high; at the ratio corresponding to the maximum specific impulse, the average density is 1.34 g/cc.

3 By decomposing all of the 90 per cent H_2O_2 catalytically, spontaneous ignition of the fuel is obtained with a delay of usually less than 0.5 sec. In this way, the combustion of the fuel may be considered as augmenting the performance of hydrogen peroxide as a monopropellant. Ignition is generally reliable and combustion is smooth over a wide range of oxidizer/fuel ratios.

4 With proper design of the engine and fuel charge, "hard" or explosive starts should never occur; the peroxide decomposition product is a gaseous oxidizer and therefore cannot accumulate in the chamber prior to ignition.

5 Intermittent operation and throttling can be accomplished by means of a single valve in the peroxide line.

6 The system has the simplicity of a monopropellant, but with safety at a given performance probably unattainable with most liquid monopropellants.

7 The design and construction of the fuel charge is not very critical in regard to the presence of cracks or voids; there is very little possibility of an explosion of the entire propellant, and in these respects the system is more desirable than most solid propellants.

There are obviously some disadvantages, such as the high freezing point and inherent instability of the hydrogen peroxide. It is difficult to vary the burning rate by more than a factor of two, which will complicate the fuel charge design in many cases. Where such limitations can be tolerated or circumvented, the many obvious advantages of the system will certainly make it very useful for some purposes.

Reactant Ratio

As applied to a solid-liquid combination, the term "reactant ratio" obviously has a somewhat different meaning from what is usually understood as the reactant ratio in other bipropellant systems. In a biliquid system, the flow of each of the two liquids is subject to essentially independent variation so that direct control of the reactant ratio is possible and is usually required. However, in the operation of a hybrid system the only variable over which any control is required, or indeed possible, is the oxidizer flow rate; the total fuel flow rate, and therefore the ratio, is determined by nature, once ignition under a given set of conditions has occurred. Moreover, one can measure only an apparent or over-all ratio, and neither the spatial nor time distribution can be determined by ordinary methods. Obviously, the fuel flow rate must be established empirically for various burning conditions, and much of the experimental work carried out was done for this purpose.

It is clear that the ratio of liquid to solid should be as high as practical, since this will allow the smallest fuel and combustion chamber, thereby minimizing the possible difficulties in obtaining complete combustion toward the end of burning. The larger the combustion chamber, the more difficult it should be to distribute the oxidizer over the fuel surface when most of the fuel has been burned.

The problem of bringing the oxidizer into contact with the fuel surface may be a serious obstacle to obtaining complete combustion with some arrangements of the solid fuel charge, but it is not insurmountable. Consideration of this point must, however, influence the ratio to be sought and therefore the choice of the oxidizer to be used. The ratio should be large, as is the case with oxidizers such as nitric acid and hydrogen peroxide which have relatively low effective oxygen content but which nevertheless give fairly good performance with many fuels. Liquid oxygen, for example, would be a poor choice in this respect, although the specific impulse to be expected is higher by 7 to 10 per cent (depending on the fuel).

The choice of the fuel should also be influenced by these considerations, though the latitude in choosing the fuel is considerably greater than it is for the oxidizer.

Presented at the ARS Semi-Annual Meeting, Cleveland, Ohio, June 18–20, 1956.

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Ignition

It is possible to obtain ignition with a pyrotechnic igniter or squib but it is highly desirable to have spontaneous ignition if possible. This might be done by appropriate coating of the fuel surface with a very reactive liquid or solid; e.g., if hydrogen peroxide were used, by coating the surface with a decomposition catalyst so that the first liquid to enter the chamber decomposes to hot steam and oxygen which could ignite the fuel. If hydrogen peroxide were the oxidizer, there is also the possibility of decomposing all of the hydrogen peroxide before it enters the combustion chamber so that the oxidizer would in effect be the steam-oxygen mixture at 740 C (for 90 per cent H_2O_2) which should ignite most combustible solids. This arrangement would possess the further advantage of preventing any possible accumulation of oxidizer in the chamber so that "hard" starts or explosions should not occur if the decomposer starts properly.

For these reasons, hydrogen peroxide (90 per cent) was chosen as the oxidizer at the outset; subsequent work has confirmed the choice as a good one. From the viewpoint of the combustion, if all the hydrogen peroxide were first decomposed, the process would involve a solid-gas reaction.

Choice of the Solid Fuel

1 Performance Considerations

Because a hybrid system possesses the simplicity characteristic of a monopropellant, a modest specific impulse would be acceptable, especially if the system also had a high average density. Thus, a realizable specific impulse of 210 lb-sec/lb at 300 psia would make it useful for many purposes. With liquid oxygen, this could theoretically be achieved with a large number of solids, but for the reasons indicated above it would be more desirable to consider nitric acid or hydrogen peroxide, with either of which a specific impulse of 210 lb-sec/lb may be attainable with a limited number of fuels. Since (for reasons given previously) hydrogen peroxide was chosen as the oxidizer, this performance could probably be obtained with a solid such as paraffin wax which should give about the same performance as would be obtained from 90 per cent H_2O_2-octane.

A number of solid hydrocarbon fuels suitable for this application which would give acceptable performance with 90 per cent H_2O_2 are available. Polyethylene, polystyrene, and rubbers of various types, such as butyl rubber and GRS (butadiene-styrene co-polymer), are examples of materials to be considered. Theoretical (frozen composition) performance curves for a number of solid fuels are shown in Fig. 1; the curve for polyethylene has been calculated over a wide range of ratios[3] since this material was selected for extensive study in the work reported here. Its composition and theoretical performance with any oxidizer are virtually identical to

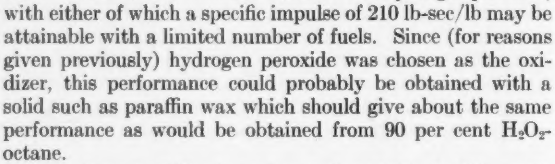


Fig. 1 Theoretical curves of specific impulse vs. reactant ratio for carbon, polystyrene, and polyethylene

[3] Some of the calculations from R_w = 7.5 to 16 were made by the Bureau of Mines, Explosive and Physical Sciences Division, Report 3182 (unclassified).

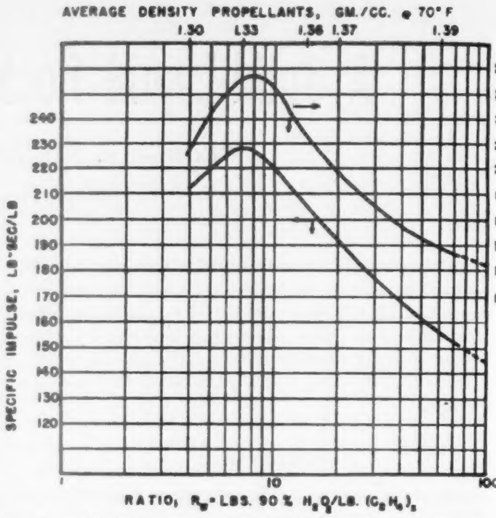


Fig. 2 Calculated curves of specific impulse and chamber temperature for the system $(C_2H_4)_x$–90 per cent H_2O_2

those for gasoline. Fig. 2 shows complete calculated curves of specific impulse and chamber temperature for the system $(C_2H_4)_x$–90 per cent H_2O_2. Average density is also given at various ratios. The curves were extended far on the side of oxidizer excess because such ratios may be of interest for gas generator application and because in this way an important feature of the system becomes evident. At $R_w = \infty$ (90 per cent H_2O_2 alone) a specific impulse of 136 lb-sec/lb is obtained; for finite R_w, the combustion of the solid fuel may be considered as simply augmenting the performance of hydrogen peroxide as a monopropellant. Moreover, if the peroxide is first decomposed, a substantial part of the over-all chemical reaction will be completed before any combustion takes place. In addititin, the attainment of nearly complete combustion should also be easier under these conditions than it would be starting from a cold liquid, such as nitric acid, liquid oxygen, or undecomposed hydrogen peroxide.

The maximum specific impulse in the polyethylene 90 per cent hydrogen peroxide system should be obtained (Fig. 1) at R_w = 7 (stoichiometric ratio, 8.1). For polystyrene the stoichiometric ratio is 7.25 and for carbon it is 6.3. Although insufficient calculations were made on polystyrene and carbon to fix their maxima in Fig. 1, they were presumed to lie in each case at about the same equivalence ratio as the maximum for polyethylene.

The ratios show that the ratio requirement indicated previously can be quite well satisfied. At the maximum specific impulse, polyethylene as the fuel would constitute only 12 wt per cent of the total propellant (18 vol per cent), so that at this or higher ratios the system would resemble a monopropellant. It seems unlikely that a more favorable ratio can be obtained with any readily available solid.

In general, fuels containing oxygen or nitrogen and having low hydrogen-carbon ratio will give low oxidizer-fuel ratio. From this viewpoint, paraffin hydrocarbons (roughly CH_2) are the most desirable common solids.

The characteristics (Fig. 2) of the system are such that it may be profitable in many applications to operate at ratios substantially higher than 7 and to accept a lower specific impulse. For example, the theoretical specific impulse at R_w = 14 is about 7 per cent lower than the maximum at R_w = 7, but the fuel and combustion chamber will be considerably smaller, since the fuel required will be reduced by a factor of nearly 2. The average density would also be increased from 1.34 to 1.36 g/cc, but this is of minor significance relative to the decrease in chamber size.

This point has influenced the work throughout, and the

emphasis has therefore been on testing at over-all ratios from the maximum toward peroxide excess (6 and higher), since there seem to be only disadvantages in operation at lower ratios.

2 Other Factors in the Choice of the Fuel

Some limitations are placed upon the solid fuels suitable for this use by the need for readily fabricated forms with good physical properties. Rubbers and plastics which can be extruded, molded, cast, machined, etc., appear to be promising from a practical viewpoint. Commercial rubbers, having a typical composition roughly $CH_{1.6}$ to $CH_{1.9}$ would probably be good fuels from the viewpoint of performance and available fabricated forms.

While some of the present work was done with rubbers of various kinds, it was decided to work intensively with polyethylene as the fuel, after the early experiments had shown promise for the hybrid system in general. While it is now apparent that other solids, e.g., rubber, might be superior in some respects, the choice of polyethylene appears to have been a good one.

3 Physical Characteristics of Polyethylene as a Solid Fuel

Since polyethylene has essentially the composition of a high grade paraffin wax, it has a heat of combustion near that of gasoline and should therefore give a theoretical specific impulse nearly the same as gasoline with any oxidizer. Table 1 summarizes the pertinent properties of the usual commercial polyethylene; this is the material on which most of the present work was done.

Table 1 Properties of commercial polyethylene

Density at 25 C	0.92 g/cc
Lower heat of combustion at constant pressure	10,359 cal/g (18,650 Btu/lb)[1]
Enthalpy of formation (per C_2H_4 unit)	$\Delta H_f^{25C} = 13{,}000$ cal/g mol[1]
Coefficient of linear thermal expansion	$1.6 \times 10^{-4}(°C)^{-1}$
Thermal conductivity	0.00074 cal/sec-cm²-(°C/cm) 2.15 Btu/hr-ft²-(°F/in.)
Melting point	110 to 120 C

[1] Parks and Mosley, *J. Chem. Phys.*, vol. 17, 1949, p. 691.

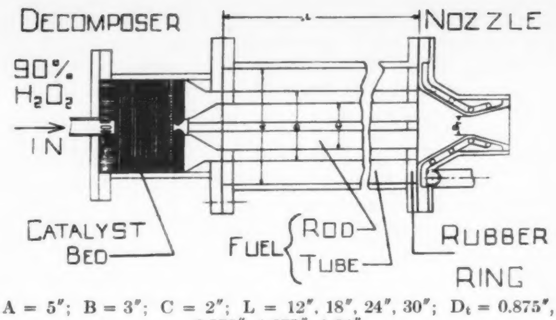
Polyethylene is a tough but readily machinable, translucent, partially crystalline plastic; the melting point corresponds to the melting of the crystalline portion, and above this temperature the viscous melt is transparent and colorless. At room temperature the material is quite resistant to chemicals such as mineral acids: it is compatible with 90 per cent H_2O_2 and is one of the recommended materials of construction for storage containers for this liquid.

Polyethylene is also available commercially in various molecular weights; these of lower molecular weight can be cast at atmospheric pressure since their melts have lower viscosities.

Test Results

A sketch of a typical test engine employed in this work is shown in Fig. 3. It has three basic components: silver screen decomposer, fuel and combustion chamber, and nozzle. In nearly all of this work, the nozzle was water-cooled. All of the fuel charges studied were internal burning, requiring no cooling of the chamber or fuel case. With the throat areas shown, the thrust in these tests varied from 250 to 1000 lb.

Starting the engine involves only the opening of a single hydrogen peroxide valve; it was always started on full flow of peroxide in these tests. The rod-and-tube type of charge (Fig. 3) permits a high loading density. It has been extensively tested for the purpose of determining performance, ratio, fuel burning rate, etc., with the various charge lengths and throat areas indicated at different chamber pressures. More than three hundred tests have been made with essentially



A = 5″; B = 3″; C = 2″; L = 12″, 18″, 24″, 30″; D_t = 0.875″, 0.972″, 1.073″, 1.24″

Fig. 3. Combustion and fuel chamber. Assembly of typical hybrid engine with rod-and-tube fuel charge

this engine, of which more than one hundred have been made with the rod-and-tube geometry shown. Other types include straight tubes (without rods) and tubes with alternating inside diameter to generate eddies for efficient mixing. Extruded tubing and assemblies of wafers, punched from $^1/_2$-in. sheet, have been used in constructing the charges.

Fig. 4 is a log-log plot of the average linear burning rate of the fuel (normal to the burning surface) correlated with a number which is roughly proportioned to the initial mass velocity of the gas in the fuel channel. These data include a range in pressure from 350 to 600 psia. The slope of the line indicates that $b \sim (G)^{0.45}$ where b is the linear burning rate and G the mass velocity. In nearly all of the tests, the burning was stopped before the charge had burned out to the case, in order to obtain definite burning times and more reproducible data for experimental purposes.

A remarkable feature of the burning of the solid fuel is its longitudinal uniformity. There appears to be no tendency for the fuel to burn faster at one end than the other. This is indeed a fortunate circumstance since premature burnout especially at the downstream or nozzle end would probably cause burnout of the metal case.

Since the polyethylene cannot be made to fit the chamber snugly at all temperatures, owing to its high coefficient of thermal expansion relative to steel, it was felt desirable to provide soft, combustible gaskets at either end (Fig. 3). These were made of 27 Durometer butyl rubber. They served to prevent longitudinal by-passing of the fuel by the decomposer gas which might result in overheating of the case.

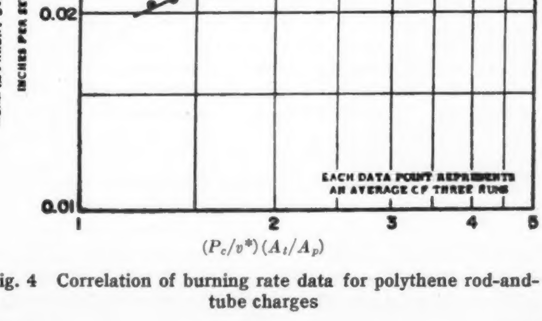


Fig. 4 Correlation of burning rate data for polythene rod-and-tube charges

Even when charges were made of wafers, leakage between and around the wafers apparently did no harm except for occasional collapse of the charge on sudden shut-down (owing to the trapping of high pressure gas between the charge and the case). As mentioned previously, such cracks and openings are not very serious; the chamber pressure is not changed materially by burning on these surfaces, as it would be with a solid propellant, because the burning is largely controlled by the oxidizer flow in the hybrid engine.

The combustion itself shows remarkable stability under all conditions, including very low chamber pressures and very low pressure drops. It appears, in fact, that the burning solid fuel is its own flameholder and a very stable one. This conclusion is supported by photographic evidence obtained with small transparent hybrid engines.

With the type of fuel charge shown (Fig. 3), a "hard" start has never been observed. From the experience gained to date it is concluded that hard starts will never occur with fuel charges which do not have longitudinal irregularities or pockets; the presence of such pockets may lead to starting difficulties under some conditions.

Acknowledgment

We wish to thank the U. S. Army Ordnance Dept. for permission to publish this paper. The investigations were conducted at various times by F. M. Cooper, D. H. Driscoll, T. C. Carnavos, and E. Ring.

Basic Concepts of Space Law

(Continued from page 957)

where personal voice-to-voice contact is neither desirable nor necessary. Such information, says Smith, is better transmitted by a teletype system, since it is possible to punch a tape of the received signal at the same time the typing section is recording the message; the taped signal may be retransmitted to the point of origin to be checked for discrepancies.

Clarke's theme is the tremendous value of radio in space navigation. He expects "astrogators," using modern electronic equipment, to steer their ships by radio beacons located on the planets and possibly in space.

The earth as a relay and master control station will be of particular significance because of the limitation on weight and volume in space vehicles. Rarely will there be "ship-to-ship" communication among space vehicles. Usually, with the space ships separated by tremendous distances, radio messages will be sent from ship to earth to ship. One reason for this is the power problem which becomes acute when considering communication with planets other than the moon. Clarke says that sufficiently large "radio mirrors" could be used to increase range—collecting and focusing usable signals without having to put up power. But it would be impractical to carry such huge equipment on space vehicles.

As we have stated above our present limited concern is with the problems of communicating with unmanned earth satellites. The problems of earth or any other remote control of an unmanned earth satellite undoubtedly will be managed within the radio spectrum already allocated to government service throughout the world. We must look forward, however, in the very near future, to the advent of the manned, earth-returnable satellite. We must also prepare to meet the well-founded contingency that states will not divert the use of the spectrum space allocated on a governmental basis to the control of and communication with either unmanned or manned earth satellites. We must be prepared to utilize the very efficient existing international agencies in the great cause of initial space communication, even though the limitations are to the aeropause and to the space familiar to the earth.

Following World War II, representatives of fourscore nations met in Atlantic City under the auspices of the International Telecommunications Union to draw up new ground rules to regulate international telecommunications.

Briefly stated, the ITU engages in four general courses of action: (1) It is instrumental in allocating radio frequencies and registering radio frequency assignments. (2) It seeks to establish the lowest rates possible, consistent with efficient service and sound financial administration. (3) It promotes measures for ensuring the safety of life through the cooperation of telecommunication. (4) It makes studies and recommendations and collects and publishes information for the benefit of its members.

To implement the work of the ITU, the Convention set up an eleven-member International Frequency Registration Board (IFRB) (a) to effect an orderly recording of frequency assignments made by the different countries and the date, purpose, and technical characteristics of each assignment, with a view to ensuring formal international recognition thereof, (b) to furnish advice to Members and Associate Members with a view to the operation of the maximum practicable number of radio channels in those portions of the spectrum where harmful interference may occur. It also set up an International Radio Consultative Committee (CCIR) to study and make recommendations on technical radio questions.[66] The Convention conferred upon its Secretariat the duty of collecting telecommunication data from sources throughout the world and suitably publishing it.

The General Regulations annexed to the International Telecommunications Convention permit scientific and international organizations to send experts to participate in ITU Conferences and work with its Committees and Subcommittees, though having no vote.[67] Moreover, the American Rocket Society, or a similar society of any other nation, may present petitions and resolutions to an ITU Conference with the consent of the official head of its national delegation.[68] The ITU has made an agreement with the United Nations whereby United Nations may be represented at ITU's conferences or committee meetings and ITU representatives may attend meetings of United Nations' General Assembly. Provision is also made for items proposed by either organization to be placed upon the agendas of the other organization or its various organs. There is also a reciprocal arrangement whereby the ITU will furnish any information which may be requested by the International Court of Justice and, in return, may request advisory opinions of the International Court of Justice on legal questions arising within the scope of its competence.

The Atlantic City Conference has recommended that the CCIR study, in particular, such questions as standardization of measurement and presentation of results of ionospheric sounding, coordination of investigations of absorption and of natural radio noise, and determination of the best practical means for rapid exchange of propagation information.

In moving toward space flight, science and government must advance more rapidly in the field of telecommunications than in any other field. Fortunately, our territorial requirements for the past century have been the same, so that a great deal of the management machinery is already set up in the various agencies of the International Telecommunications Union and through the cooperative arrangements with the United Nations.

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[66] International Telecommunications Convention, Article 8, par. 4 (3).
[67] Rule 7, par. 2 (2).
[68] Id., Rule 9.

Fiberglas-Reinforced Plastic as a Rocket Structural Material

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The M. W. Kellogg Co., Jersey City, N. J.

The application of Fiberglas-reinforced plastics to highly stressed parts such as rocket cases is described. This material is found to have a very high strength-to-weight ratio, making possible substantial weight savings. Coupled with this, secondary advantages, such as improved quality, low production labor, and lack of critical strategic materials, add to the attractiveness of Fiberglas plastics. Processes for production of rocket cases by this method are described and discussed.

1 Introduction

FOR some years, the M. W. Kellogg Co., working with the Bureau of Ordnance of the Navy Department and the Allegany Ballistics Laboratory has been designing and building structural parts for solid propellant rockets. This paper describes the application of Fiberglas-reinforced plastics to the structure of these rockets.

The design of present-day solid propellant rocket cases is a delicate balancing operation in which structural properties, precision machining, and cost of production are weighed in search of the most acceptable compromise. The importance of weight, for example, needs no explanation here; nor does the emphasis on cost of production in an increasingly competitive market. Precision machining becomes essential in many missile applications to provide accuracy of alignment during flight.

Fiberglas-reinforced plastics are of interest in this field since they offer to the careful designer an opportunity to make design improvements in weight, cost, and precision, simultaneously.

Everyone is familiar with the rapidly expanding use of Fiberglas-reinforced plastics. In the form of moldings, produced by several methods, they are applied to a bewildering variety of commercial products. In addition to production advantages, such parts offer a weight reduction, often of dramatic proportions. It is this weight reduction which initially attracts the interest of the rocket designer. As will be described, weight reduction is achievable, but only if the nature of the reinforced plastic material is carefully taken into account and a satisfactory balance is achieved between conflicting variables.

To begin, let us examine the rocket-case problem to see what properties are required. A simplified solid propellant rocket case consists of three basic components. There is a shell, which is usually cylindrical. At one end a head closes the cylinder; at the other end, a nozzle fastens to the cylinder. Gas escaping through the nozzle throat creates the required thrust.

From the standpoint of the mechanical engineer, the rocket case is a pressure vessel. The combustion of propellant takes place at high pressure, exerting tension forces on the containing walls. In most applications, the stresses due to internal pressure are dominant in determining the design. In addition to pressure forces, the parts are subjected to thermal effects: thermal shock, high temperatures, and gas erosion affect these components in one way or another.

The shell of the rocket is usually its heaviest component and will be discussed in detail in this paper. In almost every case, its chief requirement is resistance to simple pressurization stresses. Some axial bending moments occur but they are usually minor, although occasionally local attachments cause a buckling problem. In most cases, the shell is protected from the rocket flame and may be considered to be cold.

The nozzle and head also receive high pressure loads. The head usually "sees" the flame but may be insulated to prevent heating. The nozzle receives a severe thermal and erosion situation and must be very carefully designed, particularly at the throat.

These rocket parts are usually loaded briefly and for no more than two or three cycles (two hydrostatic tests and one firing). After firing, the rocket is often discarded completely. Thus, fatigue resistance is not usually important. The case must be resistant to the usual military hazards of weather, spray dirt, fungus, etc. It must not be damaged by long storage. It must operate equally well in the arctic or the tropics. It must not be easily damaged by handling.

2 Some Principles of Fiberglas-Reinforced Plastics

In applying reinforced plastics to rocket parts, certain fundamental principles must be observed if the maximum advantage is to be obtained from this material.

The term "reinforced plastic" is somewhat misleading in high strength applications. The reverse term "resin-impregnated Fiberglas" would be more descriptive, since the Fiberglas does most of the work. The structure consists of Fiberglas filaments, matted closely together, with the interstices filled with a plastic resin.

Fiberglas is made by drawing bulk glass into extremely fine fibers (0.00023 to 0.00035 in. diam). This drawing process gives the fibers an extremely high tensile strength, ranging from 200,000 to 250,000 psi. The fine filaments are gathered together in "roving," twisted into "yarn," and woven into cloth of many weaves and textures.

These fine filaments may be seen in Fig. 1, which is a microphotograph of a typical tightly wound Fiberglas-reinforced plastic. In such a structure the Fiberglas filaments are the main strength elements. The resin serves chiefly as a binder, connecting the fibers through shear bonds and giving the structure general rigidity. The resin also seals the structure.

The fibrous nature of the glass must be kept in mind by the designer; these filaments can carry load only in tension and (it is believed) only in the direction of the fiber axis. The strength of the composite in any given direction is the sum of the components of strength of all the fibers affected. For this reason, the orientation of the fibers is of extreme importance.

Presented at the ARS 25th Anniversary Annual Meeting, Chicago, Ill., Nov. 14–18, 1955.

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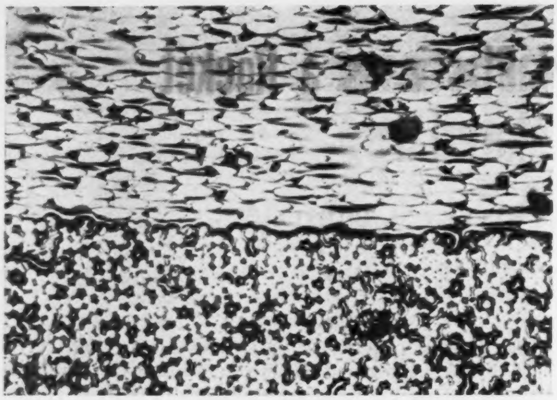

Fig. 1 Microphotograph of Fiberglas-reinforced plastic (250×)

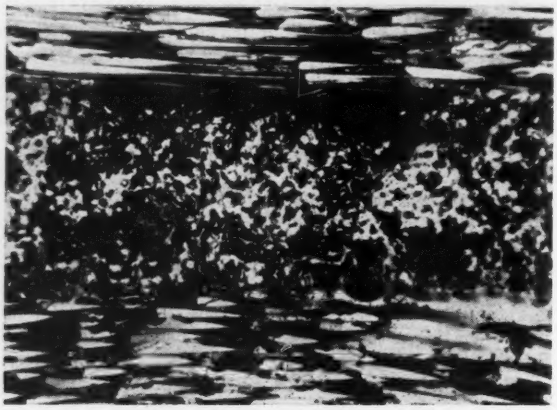

Fig. 2 Microphotograph of Fiberglas-reinforced plastic—excessive porosity (250×)

A square-weave cloth, for instance, would give equal strength in all directions, as would a randomly distributed mat of fibers. If the applied load is not equal in all directions, a suitable distribution of fiber directions can (and, for really high performance, must) be devised to fit the load pattern. This is the situation encountered in pressure vessel and rocket shell conditions.

The importance of the resin cannot be overlooked. Although it does not carry much of the tension loading on the piece, the resin does have an important role to play. Its most important function is to bind the fibers together and transfer load by shear bonds from fiber to fiber. For this reason, it must bond firmly to the Fiberglas filaments and develop a high shear strength in this bond. The resin must not peel readily away from the Fiberglas or degradation will occur on repeated loading. The resin must, of course, be resistant to exposure to the environment of the rocket in testing, storage, or use. The resin must be reasonably rigid to prevent tube distortion.

There is another resin property of importance which is more subtle. Since the resin and plastic are bonded together and depend on the bond for full strength, they must deflect together under load. Since Fiberglas loaded to capacity stretches between three and four per cent, the resin must not itself fail when stretched to this limit. Many otherwise acceptable resins are found to be too brittle to pass this requirement. Often the introduction of a modifier to increase resin elongation produces markedly improved strength.

For purposes of practicality, the resin should shrink as little as possible during curing and virtually not at all after curing. In so far as possible, the resin used should be easily handled and nontoxic. The toxicity of some of the best resins for this purpose is a continuing problem.

Of the many possible resin combinations, four general classes have proved most satisfactory for glass-reinforced service. These are all thermo-setting resins, with curing temperatures ranging from 200 F to 400 F. These resins include the epoxy, phenolic, polyester, and epoxyphenolic types.

M. W. Kellogg's direct experience has been chiefly with the epoxy resins, using Shell Epon 828 with a variety of catalysts. The epoxy resins have the outstanding property of low cure shrinkage (2 per cent or less). They bond well to Fiberglas and produce satisfactory structures. In the form used at Kellogg they need no solvent, thus minimizing porosity and permitting contact-pressure cures. The softening temperature of these resins depends on the catalyst, but is usually somewhat less than that of the phenolics. The amine catalysts used for polymerization are toxic, requiring production precautions.

Polyester resins are widely used with Fiberglas. They are somewhat cheaper then the epoxies. In the limited experience with them at Kellogg, the 7 per cent shrinkage on curing caused difficulties in mandrel removal, etc.

Phenolic resins are also widely used. The high temperature resistance of these plastics is their outstanding advantage. The use of phenolics is usually restricted to molded parts; the release of vapors in the curing process makes pressure necessary to suppress bubbling. Phenolics can be cured in two stages; the glass may be impregnated with resin beforehand and finally cured in the mold.

Recently, Kellogg has been experimenting with an epoxy-phenolic resin made by the Bakelite Co., which holds much promise. Handled like an epoxy, the resin yields good properties on contact pressure. Like the phenolics, preimpregnation is possible, with its production savings.

In addition to providing a satisfactory resin combination and the best fiber orientation, it is desirable to pack the glass as tightly as possible to provide a high bulk stress level and to conserve resin. Since the Fiberglas provides almost all the strength, the less resin used the stronger the structure. Care must, however, be exerted to prevent the resin content from getting too low so that voids appear in the structure. This leads to porosity and poor strength performance. The best compromise in most cases appears to be a mixture of 70 per cent glass by weight and 30 per cent resin.

In molding parts, high glass content can be achieved by using a high molding pressure. In built-up or wound parts, using a less viscous resin and a higher winding tension will in general increase the glass content.

3 Methods of Fiberglas Pressure Vessel and Rocket Construction

A Cylindrical Cases

To construct a Fiberglas pressure vessel in the most efficient manner the glass should be applied in a particular pattern to allow the fibers to carry as much load as possible. In a cylindrical vessel under internal pressure, twice as much load-carrying glass is required in the circumferential direction as in the axial direction. There are various methods of accomplishing this condition, a few of which will be discussed here.

Glass cloth may be used as the load carrying medium, applied as a sheet to a rotating cylindrical mandrel and impregnated with resin in the same operation. The cloth should be woven with two circumferential fibers for each axial fiber. Care must be taken to prevent wrinkling during application, since slight cloth wrinkles can start delamination during pressurization, causing premature failure of the vessel. The many cross-over points in the glass cloth weave leave void regions, making a tight packing of the composite difficult. For this reason, most cloth-wrapped units are rich in resin.

Another method employs two separate systems for carrying circumferential and axial loading. A unidirectional fiber cloth is wound on the mandrel first, capable of resisting the entire axial load. Continuous glass fibers designed to produce the required hoop strength are circumferentially wound over this base. Using this method, the cylinder may easily be locally reinforced in either direction for the purpose of resisting local loads.

This process has been successfully used and produces lightweight designs. By its nature, it is limited to cylindrical parts. Ends may be attached by scarfed and glued metal rings.

A third method, which will be more fully discussed here, consists of helically winding Fiberglas yarn on a mandrel at a predetermined angle and impregnating the weave with a suitable resin. This technique, known as filament winding, is shown schematically in Fig. 3. The winding angle θ is chosen in order to produce the correct relationship between axial and circumferential strength in the finished tube. The derivation is based on the following assumptions:

1 The load is carried by the composite structure of glass fibers and resin, both deflecting equally.

2 The fibers can carry load only along their axes. They have no bending strength.

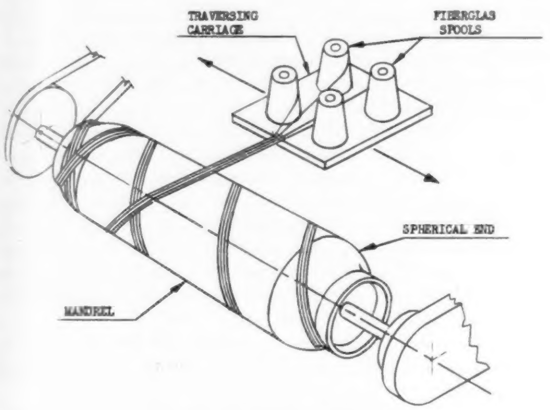

Fig. 3 Filament winding

The band of glass fibers is applied to the rotating mandrel from a traversing carriage. As the carriage reverses direction, the fibers are pulled tightly around the spherical mandrel end, thus preventing slippage. During construction, a slow precession of the carriage places each successive winding circuit adjacent to the previous one and continues until enough glass is applied to produce the required strength. The winding pattern is continuous, having only one beginning and one ending for the entire structure. It is important to note that this technique produces a wrinkle-free tube with no seam, which is actually a fabric woven on the mandrel, thus reducing the chances of delamination considerably. The use of glass in the filament condition and the continuous tight weave method of construction results in a tube with a high strength-to-weight ratio.

As the winding progresses, the matrix is impregnated with a plastic resin. It has been found that the resin content depends to a great extent on the thread tension during winding and on the viscosity of the resin as applied.

Figs. 1 and 2 are cross-sectional microphotographs of two filament-wound specimens made with normal and high thread tension. These pictures were taken with magnifications of 250× and clearly show the separate winding bands which cross each other at different angles. Each filament shown is 0.00038 in. diam. Two hundred and four filaments constitute an "end" and eight ends make up one winding strand. Fig. 2, wound with excess tension, shows a resin-starved matrix containing large voids which cause tubes of this type to fail prematurely due to porosity. The contrast between this and a normal tube, Fig. 1, is striking.

Since the resin content in any cylinder directly affects its wall thickness, the standard $P \cdot (R/t)$ calculated hoop stress can be misleading, when the stress in the glass itself is desired. The resin carries practically no load and, therefore, by considering all the load to be carried by the glass fibers, along their axes, it can be shown that

$$S_f = \frac{p\pi R^2}{NA_f \sin\theta \tan\theta}$$

where

S_f = tensile stress in each glass fiber, psi
p = internal pressure, psi
R = tube radius, in.
N = number of winding circuits (forward and back) applied in constructing the cylinder
A_f = cross-sectional area of glass in the band being applied
θ = angle of wind, with the horizontal axis

Fiberglas plastic tubes made at Kellogg by the process just described regularly develop a gross-fiber stress of 200,000 psi and have developed as much as 250,000 psi. The composite stress based on the over-all area of glass and plastic has ranged from 55,000 to 85,000 psi depending on the resin used and the resin content. In the normal range of 30 per cent resin content, the density of these tubes is about 0.06 lb/cu in. This makes the material one of the lightest known, as shown in Table 1.

Table 1 Strength-weight ratios of various structural materials

Material	Strength, psi	Density, lb/cu in.	Strength ÷ density
Steel, mild	65,000	0.283	230,000
Steel alloy, normalized	100,000	0.283	355,000
Steel alloy, heat treated	180,000	0.283	635,000
Steel alloy, strongest	225,000	0.283	795,000
Aluminum 75ST	85,000	0.10	850,000
Titanium alloy	90,000	0.16	560,000
Fiberglas plastic, current	55,000	0.060	915,000
Fiberglas plastic, eventual	75,000	0.065	1,150,000

The resin may be applied in various ways. The simplest method is actually to pour the catalyzed mixture onto the mold released mandrel during winding and manually work it into the fibers using a paddle. It is naturally more economical to set up an automatic system for application if any large number of tubes is to be made. The fibers may be run through a bath of resin before they are applied to the mandrel, but experience has shown that this method makes it necessary to drive the machine at a slow speed. Both of the above systems necessitate the use of a resin with a fairly long working life. If a resin is used which goes through various stages of cure, as in the epoxy-phenolics, it is possible to preimpregnate the glass fibers with partially cured resin before winding and administer the final cure after the tube is completed.

In early filament winding work at Kellogg, the cylindrical metal mandrel used was fabricated in axial segments which allowed the mandrel to be collapsed for removal after curing the tube. The junction lines of the mandrel segments created slight axial ridges on the internal surface of the cylinder which ultimately caused stress concentrations during pressurization. Subsequent development work resulted in a one-piece

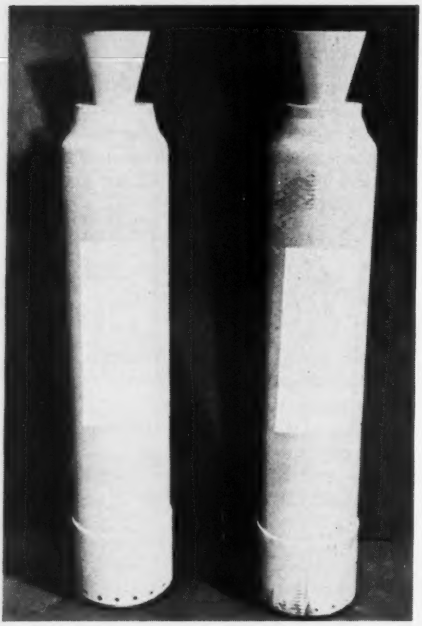

Fig. 4 Small Fiberglas-reinforced rocket tubes

Fig. 5 Large Fiberglas plastic rocket case

chrome plated tubular mandrel, tapered at an angle of approximately 1 min of arc. This type of mandrel, when properly mold released, is removed from the cylinder very easily. A smooth internal tube surface results.

The mandrels are equipped with spherical ends which are wound in tightly during the tube construction. When winding a rocket case, one of these spherical ends can be replaced by a specially designed nozzle which is wound in and remains an integral part of the unit. Two small units of this type are shown in Fig. 4. A metal end ring has been adhered to the forward end of the case for accepting the forward head. Both ends of a tube may be wound in if a fusible or collapsible mandrel is used.

Fig. 5 shows a larger diameter rocket case constructed by the M. W. Kellogg Co. using the filament winding technique, but with cemented metal end rings.

B Nozzles and Heads

As in the cylindrical case, Fiberglas-reinforced plastics find a promising application in rocket nozzles and heads. These parts are subjected to more thermal exposure, and thus resistance to high temperatures becomes as important as the basic strength at room temperature.

The head closure is readily molded in simple equipment. Although experience to date is very limited, work at Allegany Ballistics Laboratory shows much promise. Heads have been molded from small patches of glass cloth, preimpregnated with 91LD phenolic resin. These are molded under high pressure and moderate temperature to produce a dense, high quality material. Properly designed, strengths of as high as 40,000 psi can be developed. This permits a weight reduction of 30 to 40 per cent over equivalent metal parts. In production, these molded parts would be far less expensive than steel heads, since the labor charge in each piece is very low.

Rocket nozzles can be molded similarly, although indications to date are that some additional protection is needed at the throat in the form of an insert of more erosion-resistant material.

4 Summary

Based on research and development work at the M. W. Kellogg Co., and on considerations just described, the advantages and disadvantages of Fiberglas-reinforced plastic as a rocket material may be summarized as follows.

A Advantages

1 The most striking advantage, which has been discussed previously in this paper, is the exceptional strength-to-weight ratios possible when this material is used efficiently. As shown above, the use of Fiberglas permits a weight reduction of 30 per cent when compared to present practice.

2 The dimensional quality of tubes produced on a one-piece mandrel is excellent. Since the tube is cured while still on the mandrel, the internal surface of the finished tube is as true as the machined diameter of the mandrel. Recent large diameter units have been made having a maximum ovality of less than .005 in. TIR.

3 Although the raw material cost is high, the resultant reinforced plastic vessel should be cheaper than a comparative metal one because of low fabrication expenses. Unskilled or semiskilled labor may be employed, and the machinery required is relatively simple. The vessel may be completed in one step, thus eliminating expensive machining, welding, and heat treating operations. The simplicity of the filament winding technique makes it possible to install semiautomatic machinery for production work.

4 No critical materials are used in the process. The resultant product has good insulating properties and erosion resistance.

5 Reinforced plastic vessels do not shatter upon impact from bullets or similar objects, as do steel vessels. This property is desirable for military applications.

B Disadvantages

1 Two undesirable properties of reinforced plastic material are the low compression or bearing strength and its low modulus of elasticity. In standard pressure vessels, the effect of a low modulus is not too important, but in rocket application where droop characteristics are of great concern the low modulus may be disadvantageous. Since glass fibers are not good compression members, the compressive strength of a tube is approximately that of the resin itself.

2 A definite problem in reinforced plastic construction is quality control. The number and extent of voids in such a tube are difficult to determine without actually destroying the tube.

3 Most of the resins used deteriorate at temperatures above 400 F, making the vessel useless in that range if continuous service is required.

4 Toxicity of the resin is another important problem. Care must be taken to provide sufficient ventilation in vicinities where workers handle the mixtures and contact with the skin should be avoided. This is particularly true when epoxies are used.

The high strength reinforced plastic field is still in the stage of development and problems are continually being overcome. Every indication, however, shows that this is a material with a definite future in the pressure vessel field.

Combustion in the Mixing Zone Between Two Parallel Streams[1]

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Bluff body flame stabilization depends on the existence of a sheltered wake behind the body in which hot gas recirculates. The hot-wake gas ignites fresh combustible mixture; ignition occurs in a mixing zone between hot gas and external stream. Thus the mixing zone is of critical import in bluff body flameholding and demands further study. An experimental arrangement was devised to simulate important features of the bluff body mixing zone while permitting controlled study of the variables involved. The mixing zone between two parallel gas streams, one hot and one of combustible mixture, was studied. Ignition of the combustible stream was achieved with this arrangement, and many interesting phenomena were observed. Ignition was possible only above a certain temperature of the hot stream, ignition temperature depending markedly on fuel type, and related to fuel-activation energy. Burning was first seen in the mixing zone at some distance downstream from first contact of the streams. Further downstream a vigorous flame appeared that propagated into the combustible stream. The propagating flame was established only when the residence time of combustible material in the mixing zone was long enough to lead to ignition of a mass adequate to serve as a secondary ignition source. This result was applied to the explanation of bluff body flame stabilization and blowoff.

Nomenclature

- H = detachment distance of initial flame
- H' = detachment distance of propagating flame
- L = length of recirculation zone
- t = ignition time for initial flame
- t' = ignition time for propagating flame
- T_i = inner stream temperature, K
- V_i = inner stream speed
- V_o = outer stream speed
- τ = ignition time for bluff body flameholding
- ϕ = fuel-air ratio, fraction of stoichiometric

Introduction

BLUFF body flameholding depends on recirculation of hot burned gas in the sheltered wake of the flameholder. The hot gas in the wake, acting as a pilot burner, ignites fresh combustible mixture flowing by in the external stream. Ignition occurs in a mixing zone between recirculation region and external stream. Close to the flameholder the mixing zone is thin, ignition is rapid, and a true flame exists even close to blowoff. Further downstream the mixing zone is broad, and ignition is slower on the average. Only under favorable conditions is the pilot burner, i.e., the recirculation region, able to ignite a sufficient mass of gas in this part of the mixing zone to establish a self-sustaining flame that propagates into the cool stream. Zukoski and Marble (1)[4] have shown that if gas from the external stream remains in the neighborhood of the recirculation region longer than a critical time τ, a self-sustaining flame results, otherwise blowoff. The time τ depends only on the chemical characteristics of the combustible mixture and on the temperature field, not on other flow properties. This characteristic time is a similarity parameter for bluff body flameholding; there is a second important similarity parameter, the length L of the recirculation zone. Together, those two parameters provide a description of bluff body flameholding. They lead to prediction of blowoff velocity: $V_{BO} = (L/\tau)$. The important fact is that they separate the bluff body flameholding problem into two parts: chemistry (τ) and fluid dynamics (L).

The similarity parameters furnish answers to practical bluff body flameholding problems; further elucidation of details of the processes involved is required. The mixing zone is of particular importance and has been studied in several different ways. One line of attack (2) was to simulate the bluff body mixing zone by a mixing zone that was simpler and subject to control, thus permitting study of the influence of various hydrodynamic, thermodynamic, and chemical variables. The mixing zone between two parallel streams, one of hot gas and the other of cool combustible mixture, was selected for study. This arrangement successfully simulated many features of bluff body flameholding.

The experiment demonstrated that ignition in a mixing zone between a hot inert gas and a combustible mixture is possible if temperatures are high enough. The resulting flames were exceedingly interesting. A weak flame, called the initial flame, originated close to the flameholder and was confined to the mixing zone. Further downstream another flame, called propagating flame, appeared. This flame burned intensely and propagated into the cool combustible stream. The propagating flame was strongly affected by stream speeds and fuel-air ratios as well as by stream temperatures.

Study of the influence of chemical and fluid dynamic variables revealed several features that are important in bluff body flameholding. Indeed this experimental study of the mixing zone pointed the way for some of the work that culminated in the discovery of similarity parameters for bluff body flameholding.

Equipment

The parallel streams for this experiment were coaxial, the central stream hot, and the annular stream of combustible mixture. Thus, efficient use was made of the energy contained in the hot stream. The geometry was cylindric, eliminating the end and corner effects that plague rectangular configurations.

Design of the apparatus (Fig. 1) was fixed largely by the necessity for keeping the inner stream hot. The flat cylindrical burner minimized unheated length of inner stream duct.

Separate heat exchangers supplied gas for the inner and outer streams. The inner stream passed through a $1/2$-in. stainless steel tube helix immersed in the exhaust gases from a turbojet can burner. To reduce radiation losses the helix was mounted in a 6-in.-diam alundum tube that ran red, or

Received March 24, 1956.

[1] ORDCIT Project, Contract No. DA-04-495-Ord 18, Department of the Army, Ordnance Corps; Power Plant Lab. Project No. MX527, Contract No. W33-038-ac-4320, Expenditure Order No. 506-152, Air Matériel Command.

[2] Senior Research Engineer. Mem. ARS.

[3] Commander, U.S.N.

[4] Numbers in parentheses indicate References at end of paper.

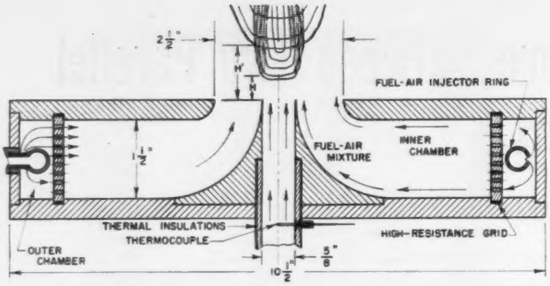


Fig. 1 Cross-sectional view of cylindrical burner

white, hot. Surface oxidation of the stainless steel tube was minimized by asbestos wrapping. This precaution assured a reasonable tube life even for operation with inner stream gas at 1300 K. Tube life decreased rapidly with increasing temperature.

The second heat exchanger was similar but simpler since it supplied air for the outer stream at a maximum temperature of 750 K. Continuous variation of temperature was achieved with the help of a cold-air by-pass. Fuel was injected into the air downstream from this heat exchanger, but far enough upstream from the burner to assure homogeneous mixing. Fuels were acetylene, propane, carbon disulphide, and Union Oil Co. Thinner #1, a gasoline-like hydrocarbon.

Combustible mixture passed through the injector ring and uniformly into the outer chamber of the burner, shown in Fig. 1. Thence, flowing radially inward through a grid and inner chamber and finally negotiating a 90 deg turn, the combustible mixture formed the outer annular stream. Convergence of the stream from grid to outlet was 30:1, and the resulting velocity pr file was reasonably flat (Fig. 2).

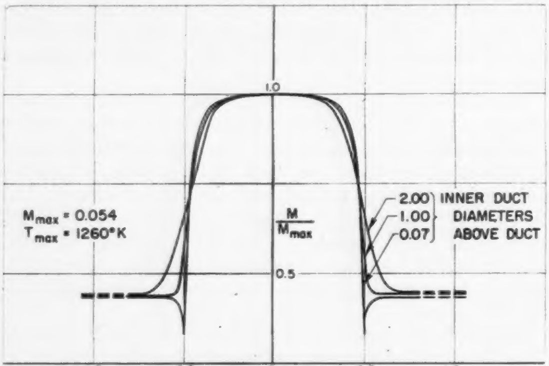


Fig. 2 Mach number distribution

Several preventative measures were taken to minimize circumferential flow in the outer stream. Cylindrical symmetry was enforced throughout; large pressure drops were maintained across the injector ring and across the grid (Fig. 1) to ensure uniform initial distributions. To eliminate large scale circumferential motions, short radial baffles were incorporated. Subsequent contraction of the flow sufficed to damp secondary flows generated by the baffles. With proper baffle adjustment no circumferential flow and no local disturbances were seen in the outer annular stream.

This stream flowed virtually parallel to the inner stream. To ensure smooth joining of the streams the flow divider terminated in a razor-sharp edge. Resulting velocity profiles were ideally flat except for thin boundary layers originating on the flow divider. Even these boundary layers had slight influence on the flames. A short distance downstream from the stream divider, and upstream from the flame, the velocity profiles were indistinguishable from those expected for initially flat distributions.

The sharp edge prevented the stream divider from acting as a flameholder. As a further precaution, the divider was water cooled.

The short length of cooled divider, Fig. 1, did not appreciably affect the inner stream temperature. Time of contact of hot gas with cool surface was so short that heat loss was slight. Resulting temperature profiles were moderately good (Fig. 3).

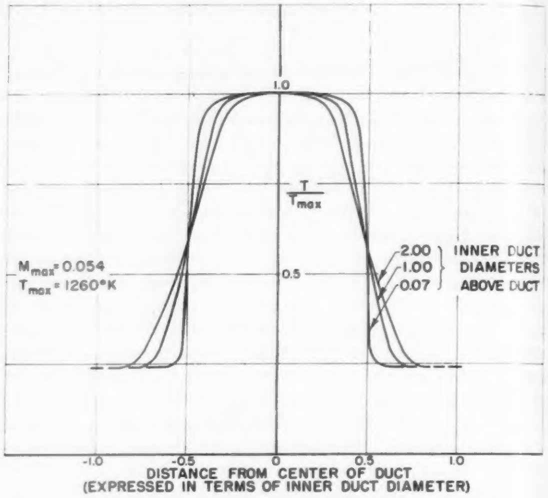


Fig. 3 Temperature distribution

The outer stream appears in Fig. 1 as a free jet and was so operated in most of the experiments. For comparison purposes, the entire stream was enclosed in a cylindrical duct. Experiments performed with this configuration showed that the external duct had small influence close to the stream divider. Further downstream, however, marked differences were observed. Flames spread less rapidly with the enclosing duct in place, and ignition distances were somewhat different for the confined propagating flame.

The cylindrical, coaxial streams provided most of the results to be reported. For preliminary observations, particularly for optical studies, a small rectangular duct proved convenient.

Observations and Results

The first important result of this experiment was the demonstration of ignition of a flowing combustible mixture by means of a stream of moderately hot gas. Ignition was achieved with an inert gas (nitrogen) but was then slightly more difficult than with air as hot gas. Hot-gas temperature necessary to produce ignition varied markedly with fuel type. An acetylene-air mixture was ignited by a hot stream at 1025 K. With propane and with paint thinner, 1205 K was required, and it was also necessary to heat the combustible mixture by 200 to 300 K before ignition occurred. On the other hand, carbon disulphide ignited much more easily than acetylene. Minimum ignition temperature was little influenced by fuel-air ratio or by gas speeds.

The marked influence of fuel type on minimum ignition temperature suggested correlation with a simple property of the fuel, perhaps the activation energy. To test the correlation hypothesis, ignition temperatures and activation energies for three fuels were compared. Assuming activation energies 16, 20, 26 K cal/mole for carbon disulphide, acetylene, and propane, respectively (3), an ignition temperature of 820 K was computed for carbon disulphide and 1333 K for propane. Experimental agreement with these values was adequate to indicate that activation energy was a dominant factor in determining ignition temperature.

The ignition established a flame, called the initial flame, in the mixing zone. This flame existed at all observable fuel-air ratios but appeared weak, particularly with very lean mixtures. Ionization in the flame, measured with an ionization probe, was small. The position of the initial flame was steady in time, its detachment distance H from the stream divider depending principally on stream temperatures and only weakly on fuel-air ratio and stream speeds (Figs. 4 and 5). Fig. 4 shows the detachment distance H plotted vs. fuel-air ratio for several outer stream speeds. Ignition time t, i.e., the travel time for a combustible particle from stream joining to ignition, was perhaps a more significant variable than H. Unfortunately, the experiments were inadequate to provide accurate numerical values for t. The average speed of the particle over the prescribed path depended on both inner and outer stream speeds. Based on a speed between these two, t was calculated to be of the order of one millisec for acetylene with inner stream at 1115 K. Experimental speed ranges were too restricted to show whether or not t was independent of stream speed, although certain results suggested this possibility.

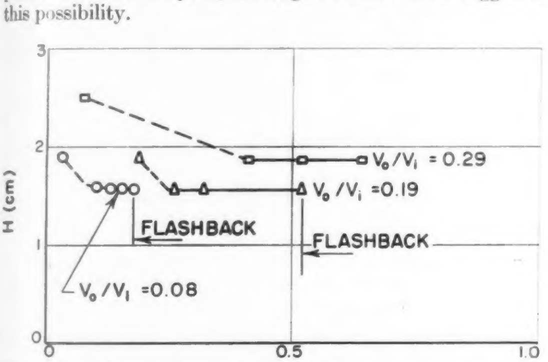


Fig. 4 Detachment distance of "initial flame" vs. acetylene-air equivalence ratio ϕ for several velocities of stream of combustible mixture V_i = 148 fps, T_i = 1115 K

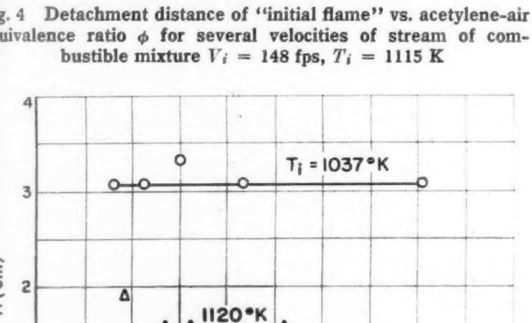


Fig. 5 Detachment distance of "initial flame" vs. acetylene-air equivalence ratio ϕ for several hot-stream temperatures V_O/V_i = 0.19, V_i = 148 fps

Fig. 4 shows an interesting feature. For constant stream speeds the detachment distance H did not change over a wide range of fuel-air ratios. Ignition time was probably constant since no lateral motion of the ignition point was observed with changing fuel-air ratios, and there was no apparent change in velocity profiles. Hence the relation between t and H did not change. Constancy of H was perhaps overemphasized by the technique of measurement since an observer tended to select standard unit values of H. In any case, changes were small. The curve, accepted at face value, indicated that at lean fuel-air ratios each fuel molecule reacted as though independent of local fuel concentration. Energy to make the reaction go was externally supplied by the hot stream, and the initial reaction did not have to supply energy to ignite fresh material as in a true flame; there was no problem of igniting a certain mass of gas for continuing reaction. In this special situation, particularly with excess oxygen, it is possible that reaction rate was independent of fuel concentration.

Initial flame observation convincingly demonstrated another result: Detachment distance increased with decreasing temperature; close to minimum ignition temperature, the increase was extremely rapid (Fig. 6). Time for ignition t likewise increased with decreasing temperature. The variation of H with temperature was perhaps best shown by plotting (H/H_1) vs. $[(1/T_1)-(1/T)]$ on semilog paper. (Subscript 1 referred to a particular set of conditions, arbitrarily chosen.) A straight line resulted: H varied exponentially with $(1/T)$ shown in Fig. 7. If, then, the detachment distance H was assumed proportional to t, the slope of the line yielded the activation energy for the process, 22 K cal/mole, to be compared with the 20 K cal/mole for acetylene given in (3).

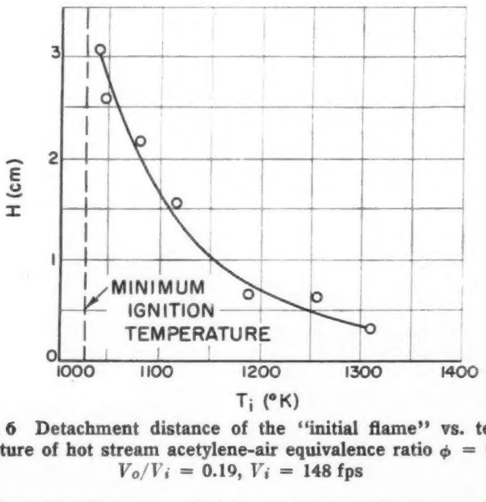


Fig. 6 Detachment distance of the "initial flame" vs. temperature of hot stream acetylene-air equivalence ratio ϕ = 0.3, V_O/V_i = 0.19, V_i = 148 fps

The initial flame provided important quantitative results; the development of the flame further downstream was also interesting. At moderate air speeds and fuel-air ratios a flame propagated from the mixing zone into the cool unburned fuel-air mixture. This flame was called the propagating flame; it burned intensely and fluctuated in space. Small as well as large fluctuations wrinkled its surface. The average distance H' of the base of this flame from the stream divider was studied as flow parameters changed. The distance depended strongly on stream temperature, Fig. 8, as did the detachment distance of the initial flame. In contrast to the initial flame distance, H' varied rapidly with stream speeds and fuel-air ratios (Figs. 9 to 11). Again the experiments were not suitable for showing whether a constant ignition time t' was to be expected for the propagating flame.

Activation energies computed in the same way as for the initial flame in general gave higher values, often twice as great, and values that varied with fuel-air ratio. The results were affected close to the stream divider by the tendency of fluctuating propagating flames to flash back into the outer duct. Other results indicated that the straight-line curves should not have been extended down to zero distance. Also, far from the splitter, the flames were influenced by changes in the external flow pattern. Although quantitative results were meager, qualitative effects were striking. Changes in H' with stream speeds, fuel-air ratios, and stream temperatures were all rapid.

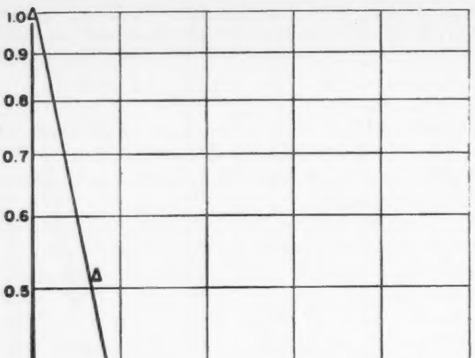


Fig. 7 Variation of characteristic time with inner stream temperature acetylene-air equivalence ratio $\phi = 0.3$, $V_i = 148$ fps, $V_o/V_i = 0.19$

Ignition of the propagating flame was a different phenomenon than ignition of the initial flame. For the propagating flame, ignition of a sufficient mass of gas to initiate a self-sustaining flame was required. "Activation energy" computed for this process would probably be higher than the true fuel activation energy. Concentration-dependent ignition times would also be expected.

Conclusions

Experiments in the mixing zone between two parallel gas streams have shown that a hot stream will ignite a stream of combustible mixture, provided the temperature of the hot stream is high enough. The time required to ignite depends critically on stream temperatures. Time is counted from the instant of first contact of the two streams. Close to the ignition point burning is confined to the mixing zone; under favorable conditions a propagating flame appears further downstream. The propagating flame is a vigorous, self-sustaining flame that propagates out into the cool combustible stream.

These findings for combustion in a turbulent mixing zone are analogous to results of calculations by Marble and Adamson for ignition in a laminar mixing zone (4). These authors showed how a slow reaction in the mixing zone finally develops a true laminar flame front that propagates into the cool combustible stream. Particularly, they showed how the time required for development depends on stream tempera-

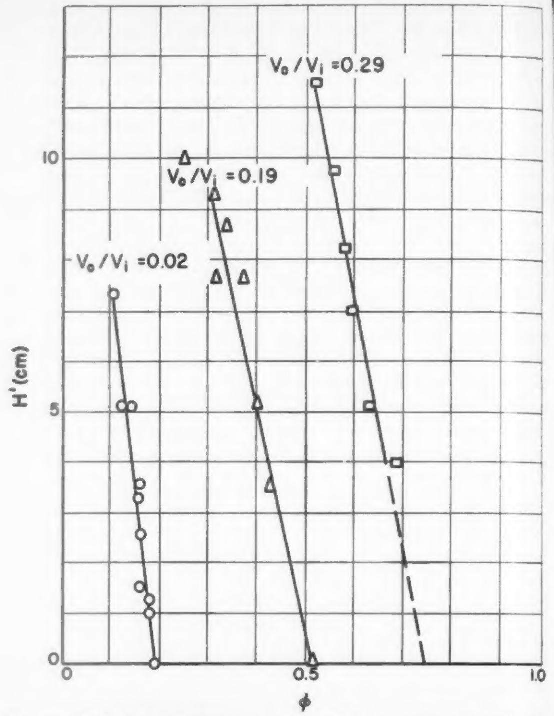


Fig. 8 Detachment distance of the "propagating flame" vs. acetylene-air equivalence ratio ϕ for several velocities of stream of combustible mixture, $V_i = 148$ fps, $T_i = 1115$ K

tures. As the hot stream temperature decreases and approaches a critical value, ignition time increases enormously. Below this temperature, ignition time is so great that no flame is seen within the bounds of any practical-size burner.

The laminar calculations are not directly applicable to experiments in a turbulent mixing zone except perhaps close to stream joining. They may indeed predict the initial flame development, but more significantly they emphasize the physical processes necessary for establishment of a propagating flame. The calculations show that a certain residence time in the mixing zone is necessary for a combustible mass to ignite and burn to the extent that this mass will in turn serve as an ignition source. Residence time required depends on factors such as activation energy and initial temperatures. In the mixing zone experiments it was clearly necessary to ignite a certain mass of combustible material; a smaller mass was quenched when surrounded by relatively cool fresh mixture.

The mixing-zone experiment was designed to simulate certain features of bluff body flameholding. Fortunately, the flames observed in the parallel-stream experiment were similar in appearance to bluff body flames (Figs. 12 and 13); thus comparisons between the two types of flame were facilitated. The counterpart of the initial flame (Fig. 12a) was perhaps the bluff body residual flame (Fig. 12b). Both flames were confined to a mixing zone and were continuously supplied with energy from a hot stream. Neither flame propagated into the cool external stream.

The bluff body residual flame existed only close to flame blowoff. A slight, favorable change in mixture strength or in flow speed produced marked changes in the flame (Fig. 13b). A propagating flame was then established downstream from the recirculation zone. The bluff body propagating flame appeared similar to the propagating flame observed in the parallel-stream experiment (Fig. 13a), except that the parallel-stream flame spread more rapidly because the outer stream was slow and because the flame was not confined. The flames of Fig. 13 look very different from the flames of

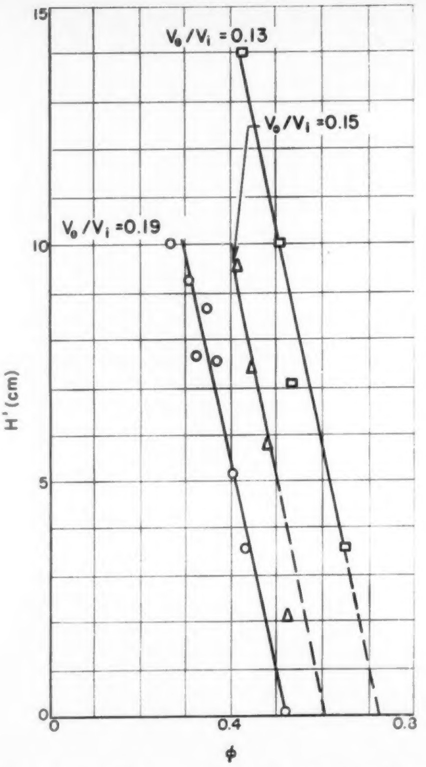


Fig. 9 Detachment distance of the "propagating flame" vs. acetylene-air equivalence ratio ϕ for several hot-stream speeds V_o = 28 fps, T_i = 1115 K

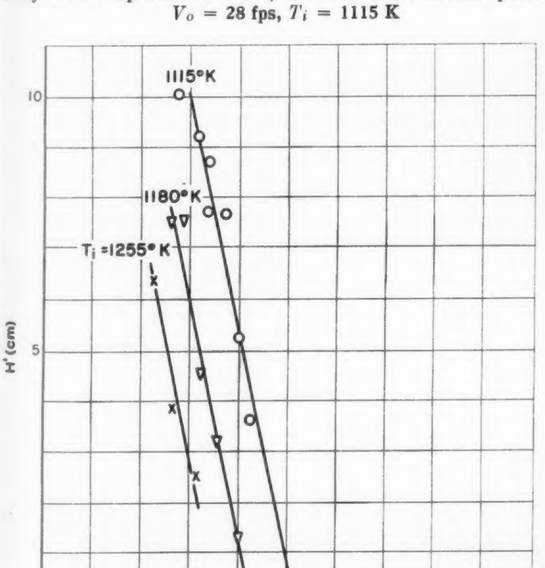


Fig. 10 Detachment distance of the "propagating flame" vs. acetylene-air equivalence ratio ϕ for several hot-stream temperatures V_o/V_i = 0.19, V_i = 148 fps

Fig. 12; yet, close to the flameholder and close to the point of stream joining, practically no change occurs. In this region the flames are confined to the mixing zone; and temperatures, velocities, and compositions are virtually the same at different mixture ratios.

These similarities between flames held on bluff bodies and

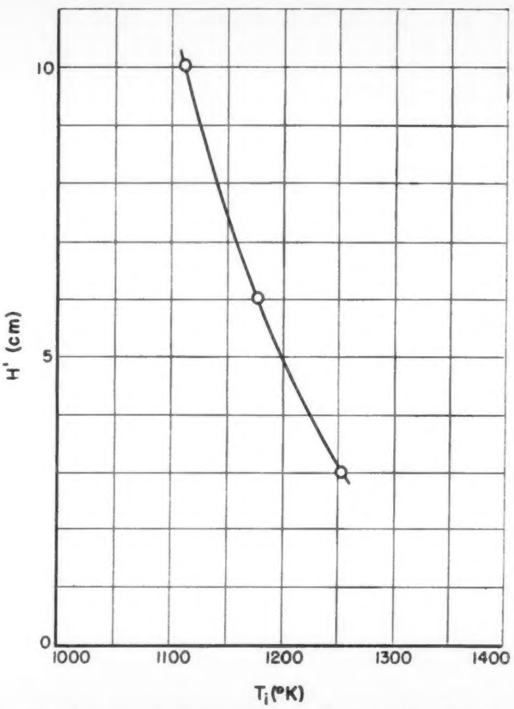
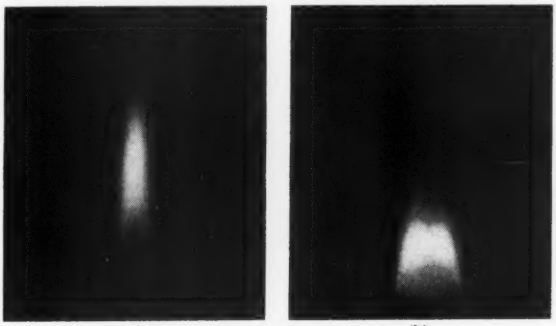
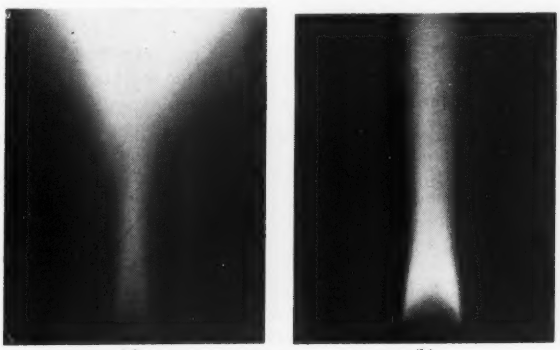


Fig. 11 Detachment distance for the "propagating flame" vs. temperature of hot stream V_o/V_i = 0.19, V_i = 148 fps, acetylene-air equivalence ratio ϕ = 0.3



(a) (b)

Fig. 12 (a) Photograph of the initial flame in parallel-stream burner; T_i = 1100 K, ϕ = 0.3, V_i = 187 fps, V_o/V_i = 0.15. (b) Photograph of residue flame held on bluff body in 2- × 4-in. duct; flameholder is 3/4-in. cylinder with axis along flow direction; $Re = 3.8 \times 10^4$, ϕ = 0.79



(a) (b)

Fig. 13 (a) Photograph of initial and propagating flames in parallel-steam burner; T_i = 1140 K, ϕ = 0.4, V_i = 187 fps, V_o/V_i = 0.15. (b) Photograph of flame held on bluff body in 2- × 4-in. duct; flameholder is 3/4-in. cylinder with axis along flow direction; $Re = 3.8 \times 10^4$, ϕ = 0.81

flames in the parallel-stream experiment lend confidence to the application of the parallel-stream results to bluff body flameholding. For the bluff body, then: Residence time in the mixing zone must be long enough to permit ignition of a combustible mass adequate to serve as an independent source of ignition for a propagating flame. Residence time *required* in bluff body flameholding is equal to the chemical time parameter τ; residence time *available* is the time spent by combustible mass in the neighborhood of the energy source, the recirculation zone. When the time available is shorter than time required, no propagating flame exists.

References

1 Zukoski, E. E., and Marble, F. E., "Experiments Concerning the Mechanism of Flame Blow-Off From Bluff Bodies," Gas Dynamics Symposium, Evanston, Ill., Aug. 22–24, 1955.

2 Wright, F. H., and Becker, J. L., "Combustion in the Mixing Zone Between Two Parallel Streams," Progress Report no. 3-25, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, June 9, 1952.

3 Fenn, J. B., and Calcote, H. F., "Activation Energies in High Temperature Combustion," Fourth Symposium (International) on Combustion, Williams and Wilkins, Baltimore, 1953, pp. 231–239.

4 Marble, F. E., and Adamson, T. C., Jr., "Ignition and Combustion in a Laminar Mixing Zone," Selected Combustion Problems, AGARD, 1954, Butterworths Scientific Publications, London, pp. 111–131.

Effect of Vibrations on Motion of Small Gas Bubbles

(Continued on page 964)

The integral in the bracket is the downward flux F through a plane on the level ξ due to the combined motions $\dot{\Delta}$ and $\dot{z}$, and the integral in Equation [a] equals $\int F d\xi$. If the plane is below the bubble, the flux F must be zero because the fluid is incompressible. If the plane is above the bubble or cuts the instantaneous position of the bubble, the flux $F(\xi)$ is the negative rate of change $-\partial B/\partial t$ of the partial volume $B(\xi)$ of the bubble below the plane, Fig. 3(b). Therefore

$$\iiint (u_\Delta + u_z)dV = -\int_0^{z+a+\Delta} \frac{\partial B(\xi)}{\partial t}\, d\xi = -\frac{\partial}{\partial t}\int_0^{z+a+\Delta} B(\xi)d\xi$$

Integrating by parts and noting that the boundary terms vanish because $B(z + a + \Delta) = 0$

$$\iiint (u_\Delta + u_z)dV = \frac{\partial}{\partial t}\int_0^{z+a+\Delta} \xi\,\frac{\partial B(\xi)}{\partial \xi}d\xi \equiv -\frac{\partial}{\partial t}\left[\frac{4\pi}{3}\,(a+\Delta)^3 z\right] \quad \text{[b]}$$

The value of the last integral was obtained by noting that it represents the negative first moment of the total bubble volume with respect to the surface.[12]

APPENDIX 2

Effect of Viscosity

As the buoyancy forces are proportional to a^3, while viscosity forces change as the surface, i.e. a^2, viscosity will enter the problem, and even control for sufficiently small bubbles. The viscous force resisting the displacement of a bubble can be expected to be proportional to the relative velocity $\dot{\xi}$ of the bubble with respect to the fluid, and therefore of the form $C(a + \Delta)^2\dot{\xi}$, where C is a constant. This force can be included in the analysis by adding such a term to [11]. In addition, it is necessary to allow for the fact that viscosity will modify the field of the flow, increasing the virtual mass of bubble by a correction factor $C_1 > 1$. Equation [11] is therefore to be replaced by

$$\frac{\partial}{\partial t}\,[C_1(a+\Delta)^3\dot{\xi}] + C(a+\Delta)^2\dot{\xi} = 2(a+\Delta)^3(\ddot{x} - g) \quad \text{[a]}$$

while the second equation of motion [15] remains unchanged. The problem can be treated as before, and oscillatory solutions exist in certain cases. The character of the solution changes only with regard to the phase of ξ with respect to x.

To see the nature of the modification consider the extreme case of very small bubbles such that the first term in [a], representing inertia effects, can be dropped

$$\dot{\xi} = \frac{2}{C}\,(a+\Delta)\,(\ddot{x} - g) \quad \text{[b]}$$

Substituting the solution [16] for Δ, the velocity becomes

$$\dot{\xi} = \frac{2ag}{C}\left[\frac{\alpha N}{6} - 1 + \left(N - \frac{\alpha}{3}\right)\cos\omega t + \frac{\alpha N}{6}\cos 2\omega t\right] \quad \text{[c]}$$

Oscillatory solutions exist again provided

$$aN = 6 \quad \text{[d]}$$

instead of the previous condition $aN = 2$. It is interesting to note that the limiting condition [d] does not depend on the value of C. When the critical depth h is computed, values about three times larger than before are found.[13]

Caution is, however, required when using [a]. By applying it to the steady rise of a bubble in a constant gravity field, it can be shown that this equation is only valid for quite small bubbles. Equation [a] leads to a linear relation between the radius and the terminal velocity which agrees with experiments for air bubbles in water only for radii of less than 0.1 cm; for larger bubbles the terminal velocity increases slowly because complicated phenomena like spiraling occur (6).

In view of the above just a rough clue whether or not viscosity will modify the results of the analysis of the main body of this paper can be obtained by comparing the velocity $\dot{\xi}$, Equation [19], and available information on the terminal velocity of rising bubbles. For bubbles between 0.1 to 1 in. diam the terminal velocity of air bubbles in water is 8 to 10 ips. Unless the velocity $\dot{\xi}$ is smaller than this value, the actual depth h can be expected to be larger than that computed from [24, 25].

References

1 Herring, Conyers, "Theory of the Pulsations of the Gas Bubble Produced by an Underwater Explosion," in "Underwater Explosion Research," vol. 2, ONR, 1950.

2 Taylor, G. I., "Vertical Motion of a Spherical Bubble and the Pressure Surrounding It," in "Underwater Explosion Research," vol. 2, Office of Naval Research, 1950.

3 Bryant, A. R., "A Simplified Theory of the Effect of Surfaces on the Motion of an Explosion Bubble," in "Underwater Explosion Research," vol. 2, Office of Naval Research, 1950.

4 Lamb, H., "Hydrodynamics," Dover, New York.

5 Bleich, H., "Longitudinal Forced Vibrations of Cylindrical Fuel Tanks," Jet Propulsion, vol. 26, Feb. 1956, pp. 109–111.

6 Haberman, W. L., and Morton, R. K., "An Experimental Study of Bubbles Moving in Liquids," *ASCE Proc.*, Separate no. 387, vol. 80, Jan. 1954.

7 Bleich, H., "Motion of Clusters of Gas Bubbles in Vibrated Vessels," Report GM-TR-27, Contract AF(600)-1190, The Ramo-Wooldridge Corp., Los Angeles, April 1956.

[12] One might be tempted to compute this integral simply by substituting the known values of u_Δ and u_z for an infinite unbounded fluid. This would lead to an incorrect result as the effect of the boundary, even if very far, contributes substantially to the value of this integral. The method of evaluation used here includes this effect.

[13] It should be noted that the dropping of the inertia terms leading to Equations [b, c] is permissible only if the bubble radius a is quite small. The expression for the relative velocity $\dot{\xi}$ contains the radius a as factor, and $\dot{\xi}$ will therefore become small compared to the over-all velocity $\dot{x}$ of the vessel and fluid. For sufficiently small bubbles an outside observer will see—in first approximation—that the bubble simply moves with the fluid. Only closer inspection will disclose the superimposed relative motion according to Equation [c]. Any sinking of the bubble must therefore occur quite slowly.

Heat Transfer and Friction Characteristics of Red and White Fuming Nitric Acid

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An experimental investigation was conducted to determine the convective heat transfer and fluid friction characteristics of red and white fuming nitric acid (RFNA and WFNA, respectively) under conditions simulating the regenerative cooling of a rocket motor. The recommended heat transfer equation for WFNA is $j = 0.030\ N_{Re}^{-0.2}$ where all physical properties are evaluated at the average bulk temperature of the WFNA. In the case of RFNA, a scale or deposit formed so rapidly in the test section no correlating equation could be determined. The decrease in heat transfer associated with scale or deposit formation in the test section was investigated for both WFNA and RFNA. With WFNA, the Fanning friction coefficients with heat transfer $f_{non\text{-}iso}$ is related to the isothermal friction coefficient f_{iso} by the relationship $f_{iso}/f_{non\text{-}iso} = (\mu_b/\mu_i)^{0.12}$. No correlation of the nonisothermal friction results could be obtained for the RFNA.

Nomenclature

A = test section flow area, sq ft
C_p = specific heat at constant pressure, Btu/lb F
D = diameter of test section, ft
f_{iso} = Fanning friction factor under isothermal conditions, $f = \Delta P g\ \gamma A^2 D/2GL^2$, dimensionless
$f_{non\text{-}iso}$ = Fanning friction factor with heat addition, dimensionless
G = weight flow rate, lb/sec
g = acceleration due to gravity, fps^2
h = film coefficient of heat transfer Btu/sq ft hr F
j = Colburn j-modulus $= h/MC_p(N_{Pr})^{2/3}$, dimensionless
k = thermal conductivity, Btu/ft hr F
L = test section length, ft
M = weight flow per unit area, lb/sec sq ft
N_{Nu} = Nusselt number $= hD/k$, dimensionless
N_{Pr} = Prandtl number $C_p\mu/k$, dimensionless
N_{Re} = Reynolds number $\rho DV/\mu = 4G/\pi g D\mu$, dimensionless
P = pressure, absolute, lb/sq in.
ΔP = pressure drop across the length of the test section, lb/sq in.
t_o = average outside surface temperature of the test section
t_i = average inside surface temperature of the test section
t_b = average bulk temperature of the acid
μ or μ_b = viscosity evaluated at the bulk temperature lb hr/sq ft
μ_i = viscosity evaluated at the average inner surface temperature of the test section
γ = specific weight, lb/cu ft
ρ = density, g/cc or slug/cu ft

Introduction

An INVESTIGATION of the heat transfer and fluid friction characteristics of white fuming (98 per cent HNO_3, 0.5 per cent NO_2, 1.5 per cent H_2O hereafter abbreviated WFNA) and red fuming nitric acid (type 3, 80–83.5 per cent HNO_3, 15 ± 1 per cent NO_2, 3 per cent H_2O, plus HF inhibitor, hereafter abbreviated RFNA) has been conducted at the Jet Propulsion Center, Purdue University, under the sponsorship of the National Advisory Committee for Aeronautics. The early investigations on WFNA, were reported in (1 and 2)[4] and summarized in JET PROPULSION (3). Since that time the investigation of WFNA has been continued and extended. In particular, the role of "scale" formation has been investigated systematically. In addition, because of interest in RFNA, an investigation was conducted with HF-inhibited RFNA over a limited range of variables. The investigation was conducted in two flow systems: a *recirculatory system* and a *single pass system.* The ranges of the variables investigated in the two systems are presented in Table 1.

Apparatus and Instrumentation

The recirculatory system, shown in Fig. 1, has been described in detail in (1 and 2). Some minor modifications were made to the recirculatory system during the series of experiments described in this paper. The chief modifications were (a) the rebuilding of the pump packing gland and impeller so that higher system pressures and test section inlet temperatures could be achieved and (b) the capacitance welding (instead of silver soldering) of the thermocouples to the test section so that higher surface temperatures could be attained.

Fig. 2 is a schematic diagram of the single pass system employed for investigating larger heat fluxes than those attainable with the recirculatory system. The diameter and length of the test section employed with the single pass system were smaller than those for the test section employed with the recirculatory system: $^3/_8$-in. diam compared to

Presented at the ARS 25th Anniversary Annual Meeting, Chicago, Ill., Nov. 14–18, 1955.

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[3] Associate Professor of Mechanical Engineering. Mem. ARS.
[4] Numbers in parentheses indicate References at end of paper.

Table 1 Ranges of variables in recirculatory and single pass systems

Variable	Recirculatory system WFNA: Reported in (2 and 3)	Recirculatory system WFNA: Current investigation	Single pass system: WFNA	Single pass system: RFNA, 14% NO_2, 0.5% HF
Reynolds modulus	55,000–220,000	38,000–318,000	232,000–524,000	42,000–210,000
Heat flux density, Btu/sec sq in.	0.13–1.4	0.11–2.2	0.86–5.13	0.34–1.88
Inlet bulk temperature	51–137	47–160	33–69	25–95
Inlet pressure, psia	64–165	65–315	495–710	90–615

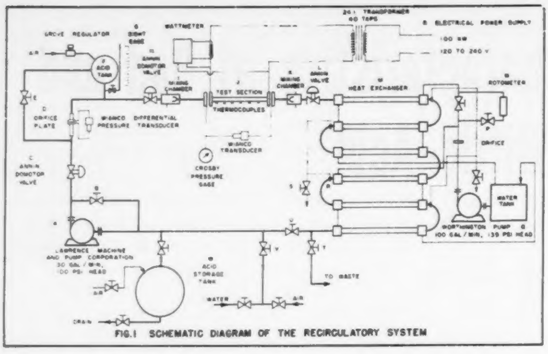

Fig. 1 Schematic diagram of the recirculatory system

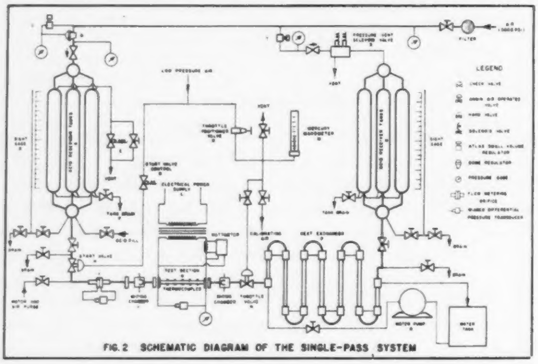

Fig. 2 Schematic diagram of the single pass system

$^5/_8$-in. diam, and 16 in. long compared to 24 in. The surface temperatures of the test section, the bulk temperatures of the acid, and the differential pressure measurements were recorded on automatic self-balancing potentiometers. The other pertinent measurements were made in the same manner as those for the recirculatory system (1, 4).

After calibrating the instruments and thermocouples, the over-all performance of the complete single pass system was investigated by measuring the convective heat transfer coefficients for deionized water. As in the case of a similar calibration of the recirculatory system, the results were in good agreement with published values.

Thermal equilibrium was established in the single pass system when operated with either deionized water or WFNA in less than 50 sec regardless of the flow rate or electrical energy input; the shortest run at the highest flow rate was 3.5 min. Equilibrium was considered established when all of the surface temperatures of the test section, as indicated by the multipoint recording potentiometer, were identical for two successive printing cycles of the potentiometer.

Results

Heat Balance

The heat energy absorbed by the acid was determined by two different methods: (a) the electrical input to the test section, which was measured by a wattmeter, denoted by q_e and (b) the energy absorbed by the acid, denoted by $q_{\Delta t}$, as calculated from the acid flow rate G, the specific heat c_p, and the average bulk temperature rise of the acid $(\bar{t}_2 - \bar{t}_1)$; thus $q_{\Delta t} = Gc_p\ (\bar{t}_2 - \bar{t}_1)$. In the ideal case $q_e = q_{\Delta t}$. Because of heat losses from the test section and also electrical losses due to electrical conduction through the acid, the value of q_e and $q_{\Delta t}$ differed from each other.

Preliminary experiments conducted with deionized water gave values of $q_{\Delta t}$ and q_e that had a maximum deviation of ± 3.5 per cent. The good agreement may be attributed to the fact that the physical properties of deionized water are known accurately and there were no losses due to electrical conduction through the water. In view of the fact that the electrical input to the test section can be measured with great accuracy, the results obtained indicate the flow rate G and the average inlet and outlet bulk temperatures $\bar{t}_1$ and $\bar{t}_2$ were measured accurately. Figs. 3 and 4 present heat balance measurements obtained with WFNA and RFNA.

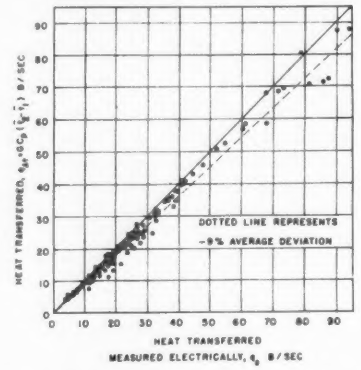

Fig. 3 Heat balance for WFNA, recirculatory and single pass systems

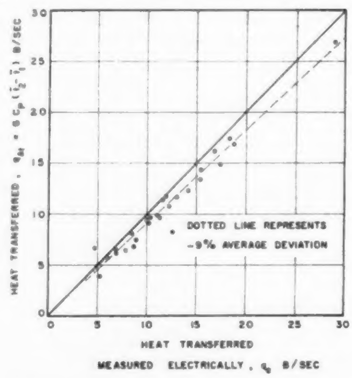

Fig. 4 Heat balance for RFNA, single pass system

The curves show that the heat energy absorbed by either the WFNA or the RFNA, $q_{\Delta t}$, is consistently smaller than the electrical input energy q_e. The afore-mentioned discrepancies between $q_{\Delta t}$ and q_e may be explained as resulting from (a) inaccuracies in the values used for the physical properties of the fluid, especially the specific heat c_p, and (b) conduction of electrical current through the acid; experiments demonstrated that the heat losses through the insulation surrounding the test section and mixing chambers are negligible (2).

The average deviation for the heat balances for WFNA and RFNA from the ideal case was -9 per cent and may be partly attributed to both of the factors (a) and (b). It was not possible to measure the magnitudes of each of these factors. The heat transfer coefficients were, therefore, calculated on the basis that the electrical input to the test section q_e was equal to the heat added to the fluid flowing through it.

Temperature Distribution in the Test Section

Fig. 5 presents typical curves of (a) the outside surface temperature of the test section t_o, (b) the calculated inside surface temperature t_i, and (c) the assumed linear variation of the bulk temperature of the acid t_b—as functions of the length of the test section measured from the test section inlet. The results shown in Fig. 5 are for measurements

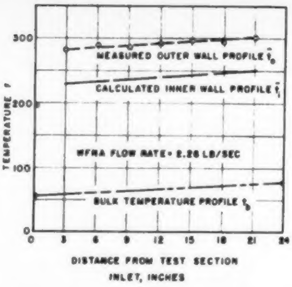

Fig. 5 **Test section temperature profile for WFNA without scale, run 4.23**

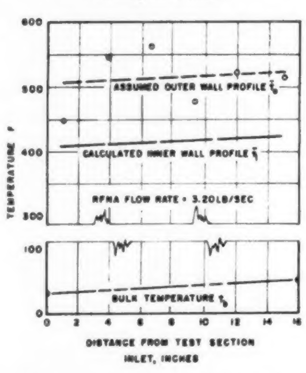

Fig. 6 **Test section temperature profile for RFNA with severe localized scale, run 15.12**

made when the test section was free from deposits or scale.

Fig. 6 presents t_o, t_i, and t_b as functions of the length of the test section for an experiment with RFNA (14 per cent NO_2) containing 0.5 per cent HF as a corrosion inhibitor. It is apparent from the figure that the temperature distribution was severely nonuniform, a condition attributed to nonuniformity of the deposits on the inside surface of the test section. Because of the nonuniformity in the distribution curve for t_o, the calculated values of t_i and the values of the heat transfer coefficient are subject to considerable uncertainty.

Scale or Deposit Formation

Throughout the experimental program the formation of scale or deposits on the inside of the test section was a perturbing problem; the decrease in the heat transfer coefficient due to scale formation was reported in (3). In the first series of test runs undertaken in this investigation with WFNA having a NO_2 content of 3.0 to 3.5 per cent (by weight), it was found that the heat transfer coefficient did not decrease, indicating that scale did not form. With WFNA of normal composition, 0.5 to 1.5 per cent NO_2, however, it was frequently necessary to flush the test section with water to avoid excessive scale formation on the inner surface of the test section. Visual observation, employing a borescope, of the deposits formed by the WFNA, indicated that they were sensibly uniform in appearance over the length of the test section. No attempt was made to determine the analysis of the deposits formed in the experiments with WFNA. It has been noted by other investigators that considerable metallic salts are dissolved in the WFNA, primarily $Al(NO_3)_3$ and $Fe(NO_3)_3$ and that these salts are probably the dominant salts in the deposits on the heat transfer surface. Since the afore-mentioned nitrates are water soluble, the fact that water removed the deposits formed during the subject experiments tends to support the above observation. A possible explanation for the formation of the deposits is the effect of a hot wall on the solubility of the dissolved metallic salts.

The rate at which deposits formed in the experiments with inhibited RFNA (containing 0.5 per cent HF) was much more rapid than in the case of WFNA. Moreover, the deposits formed with inhibited RFNA could not be removed by flushing the test section with water. It is suggested that the nonuniformity observed in the temperature distribution shown in Fig. 6 may be due to pieces of the heavy deposits breaking away from the test section wall.

An attempt was made to ascertain the chemical composition of the scale formed in the RFNA tests using both x-ray diffraction and x-ray fluorescent techniques. The analyses were performed under the direction of H. T. Yearian, Physics Department, Purdue University. The use of the x-ray diffraction did not result in the identification of any particular salts in the deposit. The x-ray fluorescent analysis revealed the presence of all of the metals contained in the alloys employed for constructing the flow system—cobalt, nickel, iron, tungsten, chromium—except aluminum. In order to gain an insight into the composition of the deposit, it was compared with the composition of the test section material (Haynes Alloy 25)[5] by comparing the strength of the $k\alpha$ emission lines from the deposit with those from the Haynes Alloy 25. The approximate relative amounts in the deposit are

Cobalt	1.0
Chromium	up 2.0
Nickel	up 1.2
Tungsten	up 1.5
Iron	up 9.0

The results from the x-ray diffraction and fluorescent analyses are not conclusive.

In studies of the passivation of the surface of aluminum containers by HF-inhibited FNA, it has been established that the protection of the surface is due to the formation of an insoluble aluminum-fluoride compound on the surface of the metal. The nature of the passivation of stainless steel alloys is, however, not definitely established (6). Whether or not the deposit formed in the heat transfer test section passivates the surface is not established; the important observation is that the deposit forms so rapidly as to constitute a very severe handicap to the regenerative cooling of a rocket motor with inhibited RFNA, if it is to operate for a relatively long period, 3 or 4 min, or for repeated periods.

Heat Transfer Results

White Fuming Nitric Acid: Fig. 7 presents the modified Colburn j-modulus as a function of the Reynolds number for WFNA. The figure presents the results of the heat transfer experiments for both clean and scaled tubes. The data obtained with the recirculatory system and

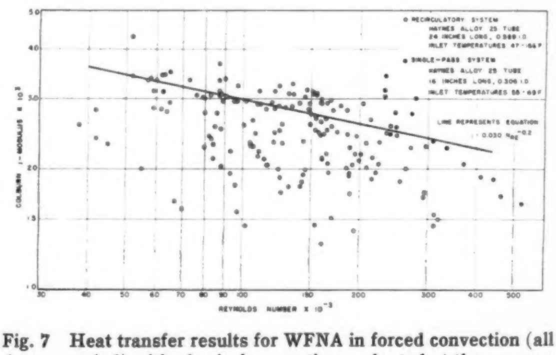

Fig. 7 Heat transfer results for WFNA in forced convection (all data recorded) with physical properties evaluated at the average bulk temperature

[5] The composition of Haynes Stellite 25 is approximately Co 50%, Cr 20%, W 15%, Ni 10%, C 0.15%, Fe 2.0%, Mn 1.5%, and Si 1.0%.

with the single pass system are indicated in the figure.

Fig. 8 presents the heat transfer results for WFNA when the test section was "clean." The clean tube data were established by utilizing a low heat flux check run before and after each series of three runs. If the check runs were identical, the data were reported as clean tube results. If the check runs were not identical, the system was flushed with water and the test runs were repeated. The "clean tube" results are correlated with an average deviation of ±10 per cent by

$$j = 0.030 \ N_{Re}^{-0.2} \qquad [1]$$

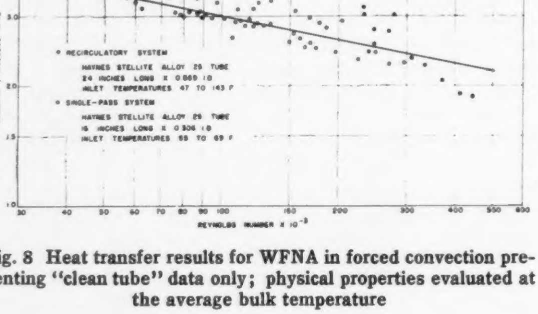

Fig. 8 Heat transfer results for WFNA in forced convection presenting "clean tube" data only; physical properties evaluated at the average bulk temperature

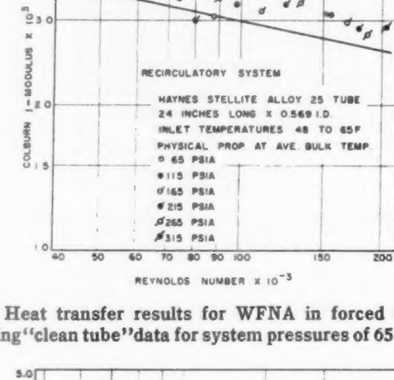

Fig. 9 Heat transfer results for WFNA in forced convection presenting "clean tube" data for system pressures of 65 to 315 psia

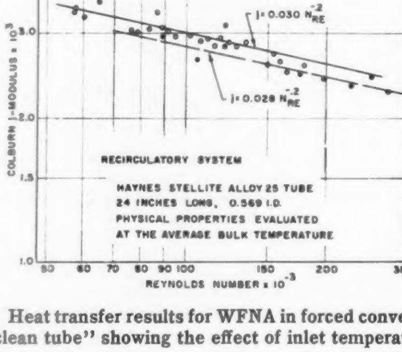

Fig. 10 Heat transfer results for WFNA in forced convection in a "clean tube" showing the effect of inlet temperature

All physical properties are evaluated at the average bulk temperature of the WFNA. The physical properties are taken from (2, 3, and 7). There was variation in the acid composition in all of the test runs, which undoubtedly contributed to the scatter of the results. It is interesting to note, however, that change in the composition during a series of runs with the same acid was less than the variation in the acid as received from the manufacturer. The maximum variation in acid composition was obtained in a series of 19 experiments with the same acid; the composition of the WFNA varied as follows:

	Before	After
NO_2	0.16	0.72
H_2O	1.6	2.1
HNO_3	98.24	97.18

Since the physical property variations with composition are not accurately known the variation in composition was always neglected.

The coefficient in Equation [1] is 25 per cent higher than that recommended in (2 and 3); the latter was recommended as a conservative value since the effect of scale had not been established.

The "clean tube" results are correlated equally well by the Sieder and Tate equation

$$j = 0.027 \ N_{Re}^{-0.2}\left(\frac{\mu_b}{\mu_i}\right)^{0.14} \qquad [2]$$

where

μ_b = the viscosity of the WFNA at the average bulk temperature of the WFNA

μ_i = the viscosity of the WFNA at the average inner surface temperature of the test section.

All physical properties in Equation [2], except μ_i are evaluated at the bulk temperature. Equation [2] was recommended by E. Ashley for correlating the results of his investigation with WFNA in an annular test section (5).

Effect of Inlet Pressure. Several series of heat transfer experiments were conducted at inlet pressures of 65, 115, 165, 215, 265, and 315 psia with a constant WFNA inlet temperature of 50 F. The results are presented in Fig. 9. All of the results shown in Fig. 9 were obtained in the recirculatory system. There is no systematic trend indicating that the static pressure of the WFNA has a significant effect on the heat transfer, even though all but 2 points in Fig. 9 are higher than the correlating equation established at 65 psia. All of the pressure tests were conducted under clean tube conditions.

Effect of Inlet Temperature: Fig. 10 illustrates the effect of the bulk temperature of the WFNA at the inlet to the test section upon the heat transfer to the WFNA for the case where the test section could be considered to be in the "clean tube" condition. The data were obtained with two different inlet bulk temperatures, 50 and 139 F, and the experiments were conducted with the recirculatory system. It is seen from Fig. 10 that the 89 F difference in the inlet bulk temperature decreased the coefficient in Equation [1] from 0.30 to 0.28. The test runs with the inlet temperature of 139 F were conducted at a pressure of 115 psia.

When the results of the temperature investigations are correlated by the Sieder and Tate equation (Equation [2]) it appears that the average inlet bulk temperature of the WFNA has no influence on the correlation, at least for the inlet temperatures of 50 and 139 F.

Red Fuming Nitric Acid: The only physical property data reported in the literature for RFNA are the viscosity and density system of HNO_3, NO_2, and H_2O (8). Since no data on specific heat and thermal conductivity could be found, the values of specific heat and thermal conductivity determined for WFNA at Purdue University (7) were employed for RFNA.

Fig. 11 presents the Colburn j-modulus as a function of the

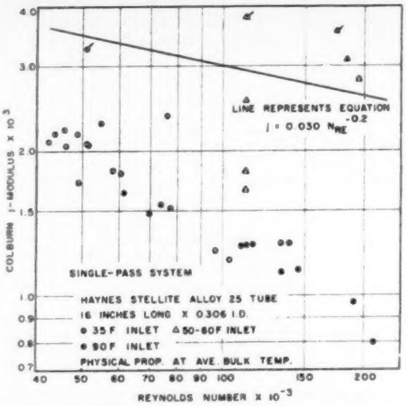

Fig. 11 **Heat transfer results for RFNA in forced convection at inlet temperatures of 35 to 90 F**

Reynolds number for the RFNA investigation. It is apparent that the results do not correlate. The lack of correlation is attributed to the rapid and severe scaling of the inside surface of the test section in all of the RFNA experiments. The three points in Fig. 11 indicated by the dash are "clean tube" points; that is, these were the first results obtained with new test sections. The line in Fig. 11 represents the equation $j = 0.030\ N_{Re}^{-0.2}$. It appears probable that "clean tube" results would be correlated by this equation.

Effect of Deposits on Heat Transfer Characteristics

An investigation was conducted on WFNA and RFNA with the objective of determining the rate at which the deposits were formed, as indicated by the decrease of the Colburn j-modulus. The investigation with WFNA was conducted in the recirculatory system and also in the single pass system. The investigation with the RFNA was conducted in the single pass system.

Fig. 12 presents the Colburn j-modulus for WFNA as a function of time (recirculatory system) and shows the effect of the deposits. At a Reynolds number of 150,000, the outside tube temperature t_o was held constant at 300 F. As deposits were formed it became necessary to reduce the heat flux density in order to maintain the constant value of t_o. The Colburn j-modulus decreased 40 per cent after 100 min of running and the heat flux density had to be reduced from 0.83 to 0.53 Btu/sec sq in.

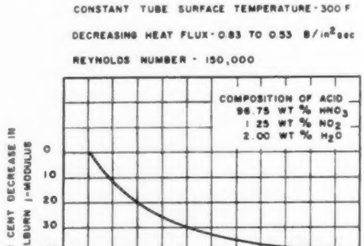

Fig. 12 **The effect of deposits on the Colburn j-modulus for WFNA as a function of time; recirculatory system; runs 9.90 to 9.95**

Fig. 13 presents the same type of information for WFNA from experiments conducted in the single pass system. Because of the limited supply tank capacity, the flow rate and electrical energy were held constant and the outside temperature t_o was allowed to increase as deposits were formed on the inside wall of the test section. The results indicate that in a single 14.5-min run at the heat flux density of 0.6 Btu/sq in. sec and a Reynolds number of 62,000 there was no decrease in the Colburn j-modules. When the heat flux density was increased to 1.8 Btu/sq in. sec and the Reynolds number to 250,000, the Colburn j-modulus decreased by 5 per cent in a period of 15 min. In the test at the higher Reynolds number (higher flow rate) it was necessary to make three "passes" to achieve the total running time of 15 min. Consequently, the test section was "reverse flushed" twice with acid, since the acid was forced from the receiver tanks back into the reservoir tank through the flow system and had probably removed some of the deposit.

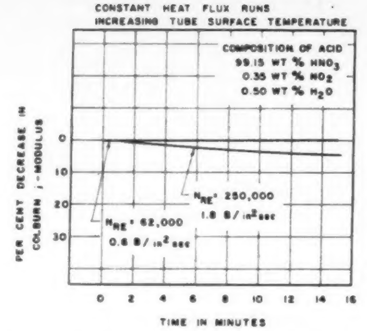

Fig. 13 **The effect of deposits on the Colburn j-modulus for WFNA as a function of time; single pass system; runs 18.01 to 18.04**

Figs. 12 and 13 indicate that for a regeneratively cooled rocket motor which employs WFNA as a coolant the deposits formed during the heat transfer process do not affect the heat transfer significantly if the total operating time for the rocket motor is less than 15 min. If the same motor is to be used several times, as in an assisted take-off application, it would be advisable to remove the deposits periodically.

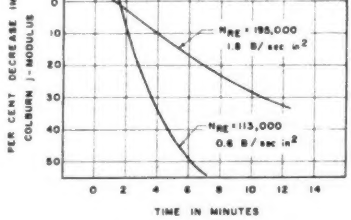

Fig. 14 **The effect of deposits on the Colburn j-modulus for HF-inhibited RFNA as a function of time; single pass system; runs 18.05–18.09**

Fig. 14 presents the results of experiments concerning the effect of scale formed in the case of RFNA with 14 per cent NO_2 and 0.5 per cent HF. The experiments with the inhibited RFNA were conducted in the same manner as the experiments with WFNA in the single pass system. With a constant heat flux density of 0.6 Btu/sec sq in. and a Reynolds number of 113,000, the Colburn j-modulus decreased 55 per cent during a 7-min period of operation. When the heat flux density was raised to 1.8 Btu/sec sq in. and the Reynolds number to 195,000, the Colburn j-modulus decreased 32 per cent in 12 min of operation. The reason for the rather surprising reduced rate of scaling at the high heat flux was not determined. Two possible explanations are: (a) The threefold increase in velocity in the high heat flux run caused pieces

of the deposits to break away from the wall, or (b) the "reverse flushing" necessitated by the higher flow rate dissolved some of the deposits in the RFNA. In all of the experiments with RFNA, the effect of scale upon the outside tube surface temperature t_o was noticed almost immediately after the electrical energy was supplied to the test section. In the case of RFNA, the deposits were not soluble in water and consequently it was necessary to mechanically clean the test section between runs. Because of these deposits and the difficulty associated with removing them, the heat flux density below which no deposits are formed was not determined, assuming such a condition exists.

The Pressure Drop Due to Fluid Friction

The isothermal pressure drop due to fluid friction for WFNA is presented in Fig. 15 where the isothermal Fanning friction coefficient f_{iso} is plotted as a function of Reynolds number; the fluid properties are evaluated at the average bulk temperature t_b. The solid line in Fig. 15 represents the experimental data reported by L. F. Moody for smooth tubes (9).

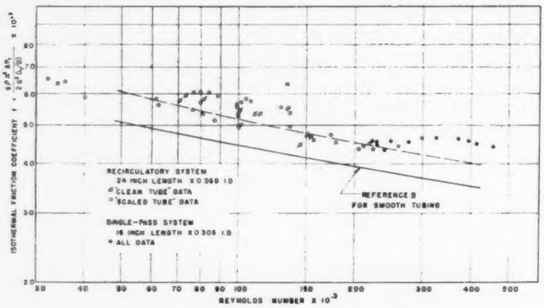

Fig. 15 Isothermal Fanning friction coefficient for WFNA

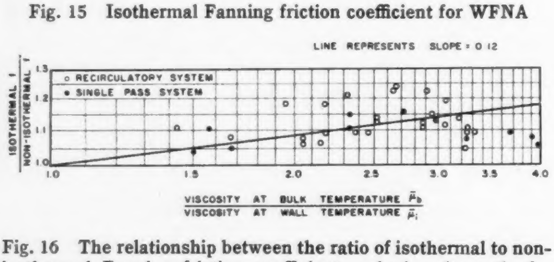

Fig. 16 The relationship between the ratio of isothermal to nonisothermal Fanning friction coefficient and viscosity ratio for "clean tube" WFNA data

The equation relating the isothermal and nonisothermal pressure drop data at the same Reynolds number for the "clean tube" results is

$$\frac{f_{iso}}{f_{non\text{-}iso}} = \left(\frac{\mu_b}{\mu_i}\right)^{0.12} \quad \ldots\ldots\ldots\ldots\ldots\ldots [3]$$

Fig. 16 presents the experimentally determined values of the ratio $f_{iso}/f_{non\text{-}iso}$ as a function of the viscosity ratio μ_b/μ_i. It can be seen that Equation [3] correlates the results satisfactorily although some of the points deviate by ± 10 per cent.

Fig. 17 presents the Fanning friction coefficient for RFNA as a function of Reynolds number for both the isothermal and nonisothermal case. The isothermal data are correlated satisfactorily by curve A. The results of (9) are presented for comparison. The isothermal experiments were performed in an initially clean test section with RFNA with an average bulk temperature of 35 F. Consequently, it is believed that only a small amount of scale was formed and the isothermal results are considered "clean tube" results.

It was not possible to correlate the results of the nonisothermal investigation for RFNA. Experiments with a

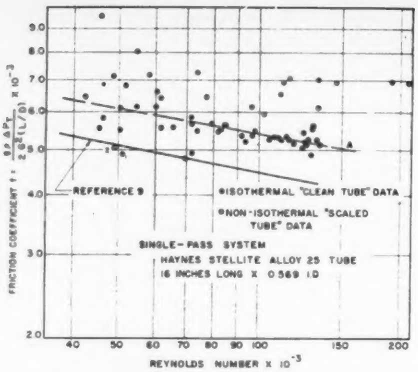

Fig. 17 Comparison of isothermal and nonisothermal Fanning friction coefficients for RFNA

number of fluids have shown that the nonisothermal friction factor is always smaller than the isothermal friction factor for the same conditions of surface roughness. The points labeled 1 and 2 in Fig. 17 are considered "clean tube" data and they fall below the isothermal results. Almost all of the other nonisothermal friction coefficients are higher than the isothermal coefficients. The larger values of the friction coefficient for the nonisothermal experiments for RFNA are attributed to the increased surface roughness due to the deposits on the inside wall of the test section.

Conclusions

The main conclusions drawn from the experimental investigation of the heat transfer characteristics of WFNA and RFNA in forced convection in horizontal tubes are:

1 The heat transfer results for WFNA over a Reynolds number range from 57,000 to 440,000 and with heat flux densities ranging from 0.11 to 4.6 Btu/sec sq in. can be correlated with an average deviation of ± 10 per cent by the equation

$$j = 0.030\, N_{Re}^{-0.2}$$

where all physical properties of the WFNA are evaluated at the average bulk temperature.

2 Increasing the inlet temperature of the WFNA from 50 to 130 F resulted in a decrease in the coefficient in the above equation from 0.030 to 0.028. If the Sieder and Tate equation is used for correlating the heat transfer results, no correction for inlet temperature is required.

3 Increasing the inlet pressure of the WFNA from 65 psia to 315 psia has no effect upon the heat transfer.

4 In runs of short duration with WFNA (less than 15 min) and moderate heat flux densities (less than 1.8 Btu/sec sq in.), scaling of the test section does not appear to be a serious problem. At a heat flux density of 1.8 Btu/sq in. sec and a Reynolds number of 250,000, the reduction in the heat transfer coefficient was 5 per cent. In another experiment with an average heat flux density of 0.68 Btu/sq in. sec and a Reynolds number of 150,000, the decrease in heat transfer coefficient in 15 min was about 15 per cent. The decrease in heat transfer coefficient increased with operating time and with heat flux density. The deposition rate appears to be a function of acid composition, heat flux density, bulk temperature, and Reynolds number.

5 In the case of RFNA (14 per cent NO_2, 0.5 per cent HF), the rate of scaling was so rapid that very few "clean tube" data could be obtained. These few data indicated that the standard correlation

$$j = 0.030\, N_{Re}^{-0.2}$$

(Continued on page 990)

Mollier Charts for the Decomposition of Hydrogen Peroxide–Water Mixtures[1]

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This report presents Mollier charts for the decomposition products of hydrogen peroxide–water mixtures at weight concentrations of 70, 80, and 90 per cent. The Appendix deals with methods used to relate decomposition products of hydrogen peroxide as a heterogeneous system to data published by the Bureau of Mines.

Nomenclature

C = concentration by weight of hydrogen peroxide
c_p = specific heat at constant pressure
h = specific enthalpy
Δh = available energy (or change in specific enthalpy in an expansion process)
ΔH_f = heat of formation
I_{sp} = specific impulse
J = mechanical equivalent of heat
n = mols
P = pressure
R = specific gas constant
s = specific entropy
T = temperature
u = velocity
v = specific volume
V = volume
W = weight
X = water vapor quality (ratio of weight of water vapor to total weight of water)
Δ = increment or difference

Subscripts

c = conditions in reaction chamber
e = exhaust conditions
0 = at 0 K
p = propellant

Introduction

The Bureau of Aeronautics, in cooperation with the Office of Naval Research, has been sponsoring a project at the Bureau of Mines for calculation of the composition and thermodynamic properties of rocket propellant combustion gases. The resulting tables of thermodynamic properties are potentially of great value to the rocket field. However, they are not in a form that can be used readily for rocket propellant performance calculations. In order to make tabulated data of this type more useful, NARTS has initiated a program to plot the data in Mollier chart form. Two factors are included to facilitate use of the charts. These are total heat content of the entering propellants (liquid phase) over a temperature range of -40 to $+80$ C and total heat content of the propellants at 0 K.

Received Dec. 13, 1955.

[1] Permission granted by the Power Branch, Office of Naval Research, to use thermodynamic data computed by the Bureau of Mines under ONR contract in the preparation of the Mollier Charts included in this paper.

[2] Projects Group Leader, Engineering Dept. Associate Fellow, IAS.

[3] The molecular weight of the hydrogen peroxide systems is constant for each chart.

[4] Numbers in parentheses indicate References at end of paper.

This project, authorized under BuAer Project TED-ARTS-SI-505.6, will be conducted on a continuing basis as thermodynamic data are received. This first report deals with Mollier charts for the decomposition of 70, 80, and 90 per cent concentration by weight of hydrogen peroxide.

Significance of the Mollier Chart

A Mollier chart is a plot of state points of a fluid under equilibrium conditions. Parametric curves of pressure, temperature, and molecular weight[3] are plotted on a grid of specific enthalpy (heat content) versus specific entropy. Provided is a rapid and simple technique for finding the energy available for conversion to kinetic energy in a given expansion process. In rocket performance calculations, specific impulse may be determined from the square root of the available energy in accordance with Bernoulli's theorem

$$\Delta h = h_c - h_e = u^2/2gJ$$

and since $I_{sp} = u/g$

$$\Delta h = I_{sp}^2 g/2J$$

Substituting consistent values for g and J, we have

$$u = 300\sqrt{\Delta h},\ \text{ft/sec}$$

and

$$I_{sp} = 9.33\sqrt{\Delta h},\ \text{sec}$$

where Δh is in units of cal/gm.

The ideal velocity and specific impulse of a propellant are determined by finding the enthalpy difference along a constant entropy path between the reaction pressure and the exhaust pressure, and by applying the appropriate equations as shown above. Initial enthalpy, determined by the temperature of the entering fluid(s), is found from the grid in the upper left-hand corner of the chart.

Mollier Chart Construction

In (1),[4] thermodynamic properties of decomposition products of hydrogen peroxide are based on a homogeneous system; that is, the water and oxygen products of reaction are treated as a single phase (gas) system. The data thus derived are only accurate in areas of high temperature and low pressure. Ref. (2), which deals with a heterogeneous system, does not present data in the region of interest of the Mollier charts. To permit broader application of the Mollier charts and for specific use in rocket work, it becomes necessary to consider water in the vapor and liquid state.

From (1), the pressure and temperature lines (shown in Table 1) as functions of enthalpy and entropy were checked and found to be homogeneous (gaseous) in nature and were, therefore, used in the preparation of the Mollier charts.

The Bureau of Mines' calculations are based upon the methods of Brinkley (3 and 4) and Beattie (5). These calculations employ values of the thermodynamic properties of

the constituent gases recommended by the National Bureau of Standards (6). Specific enthalpy values were determined relative to the elements in their standard state at 0 K. Physical properties of hydrogen peroxide and water have been taken from published tables (7 and 8).

Quality lines were calculated by the method given in I of the Appendix. Temperature lines covering the superheated steam region were computed according to the method given in the Appendix, II.

The pressure lines drawn from (1) as a function of enthalpy and entropy were checked for agreement with the calculated temperature lines by selecting a state point (T and P) from the chart and independently computing the entropy. The method of calculation is shown in III of the Appendix.

At higher pressures, solubility of oxygen in water and deviations of oxygen from perfect gas theory were checked and found to be negligible.

Data were extended into pressure regions lower than 100 psia by means of the relationship

$$dh = Tds + vdP$$

which, by means of perfect gas theory, reduces to

$$\Delta s = -R \ln (P_2/P_1) \text{ for } T = \text{const}$$

and

$$\Delta s = c_p \ln (T_2/T_1) \text{ for } P = \text{const}$$

Total Heat of Unburned Propellants as a Function of Propellant Temperature

The Mollier chart must present information on the total heat of unburned propellants as a function of propellant temperature. This provides the means for locating the state of the gases after decomposition and prior to expansion. The following steps were used to derive these data:

1 The total heat of the unburned propellants at 65 F (18.3 C) are listed in Table 2 of (1) as the specific enthalpy corresponding to the flame temperature. The enthalpy values were checked and found to agree with propellant entry in the liquid phase.

2 Given total heat content at a propellant temperature of 18.3 C, it is merely necessary to compute the change in enthalpy over the desired propellant temperature range, −40 to +80 C. The change in enthalpy was found from the relationship

$$\Delta h = c_p(T_p - 18.3)$$

Values of c_p for hydrogen peroxide–water mixtures were available in Fig. 3 of (9).

Table 1 Pressure and temperature lines as functions of enthalpy and entropy

Concentration by weight of H_2O_2, %	Temperature (°K) lines	Pressure (psia) lines
90	500,[1] 550,[1] 600 to 1100 in 100 increments.	100 to 500 in 50 increments; 500 to 1500 in 100 increments; 1500 to 3000 in 500 increments
80	none	same as above
70	none	same as above

[1] Required slight modification at the higher pressures.

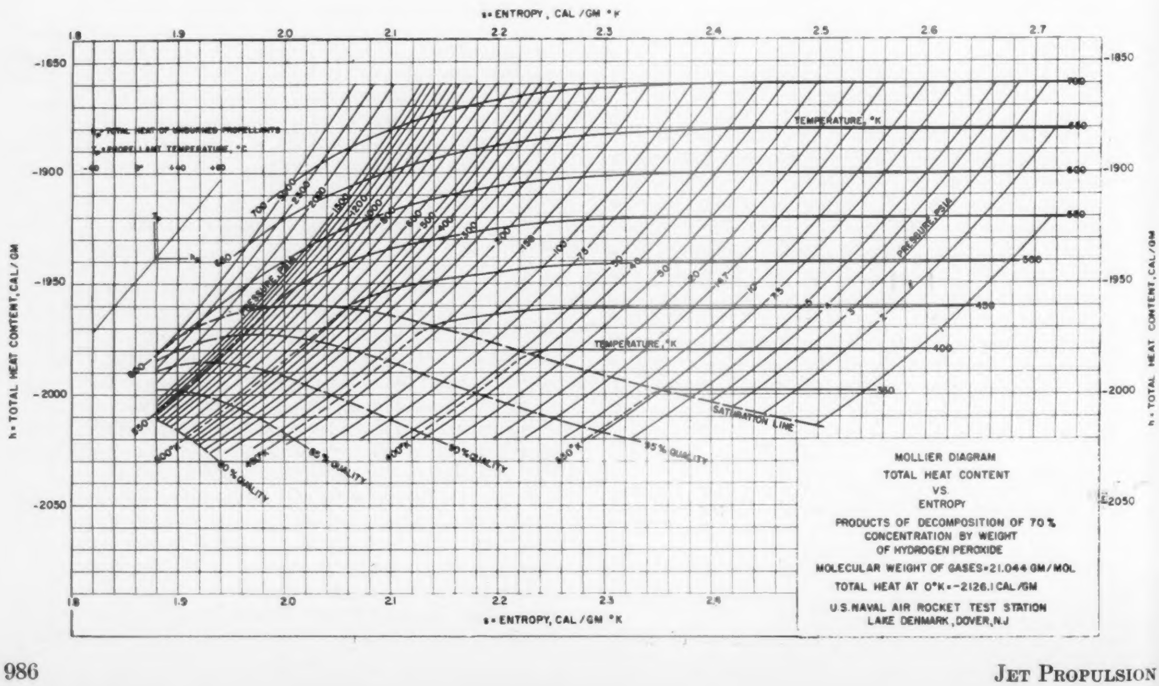
Total Heat at 0 K

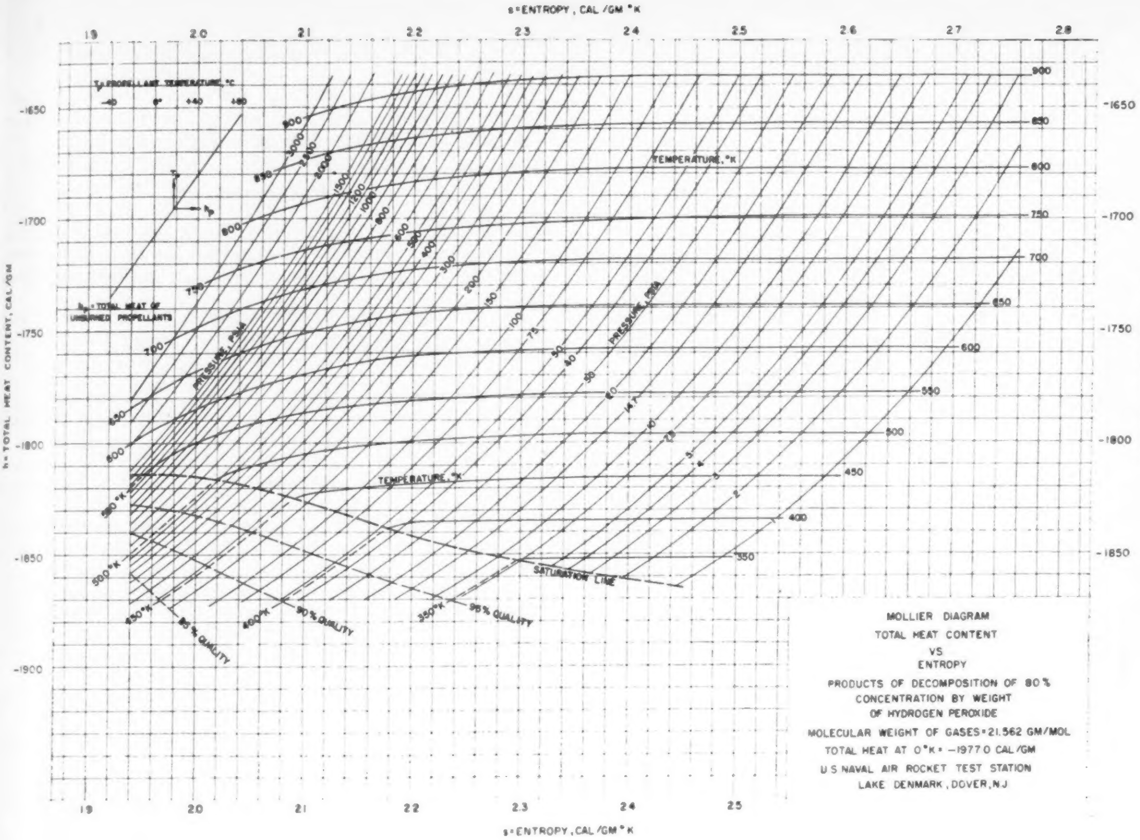
At zero pressure and temperature, the enthalpy will be zero. The average total heat of the product gases will be the summation of partial molar heats of formation of the component gases at 0 K. The products of decomposition of hydrogen peroxide–water mixtures yield H_2O and O_2. The heat of formation for O_2 at 0 K is zero. Therefore, the total heat content of the decomposed gases at 0 K becomes

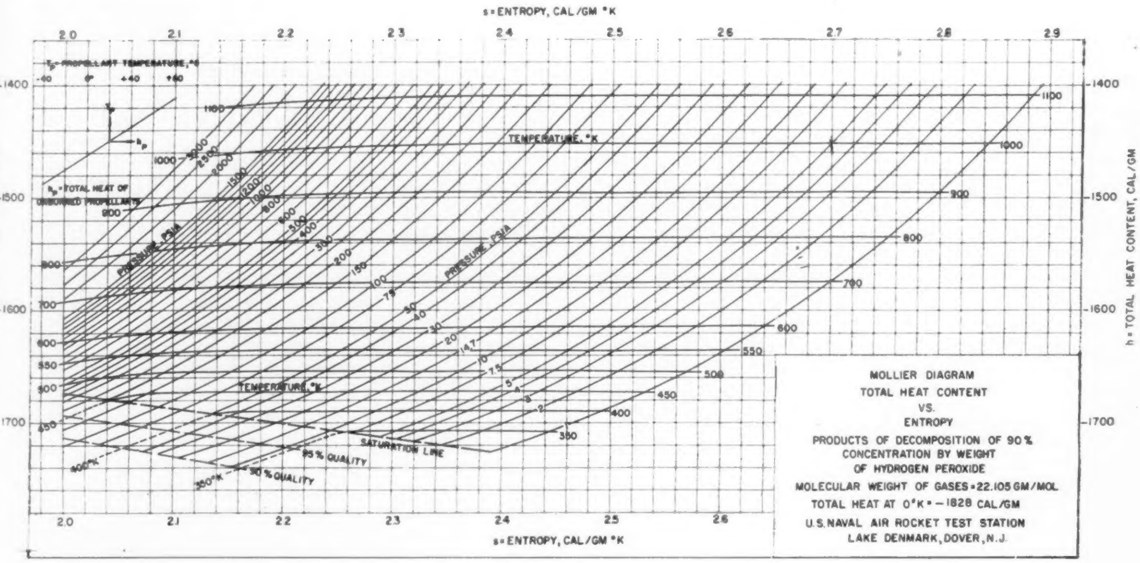
$$h_0 = n_{H_2O}(\Delta H_{f_0})_{H_2O}$$

with (see Ref. 6)

$$(\Delta H_{f_0})_{H_2O} = -57{,}107 \text{ cal/mol}$$







APPENDIX

I Procedure for Calculating the Saturation State or Wet Region (Development of Water Vapor Quality Lines)

1 Assume a value for temperature T and quality X.

2 For the selected value of T and X and from (10), determine the vapor pressure (or partial pressure) P_{H_2O}, the specific enthalpy h_{H_2O}, and the specific volume v_{H_2O} of water. The enthalpy value is modified from a zero base at 32 F liquid state, to a zero base at 0 K gaseous state, for use with the data of (6) and in these Mollier charts.

3 In a mixture of decomposed products the total volume occupied by the individual constituents must be equal, i.e., $V_{H_2O} = V_{O_2}$. It follows that

$$v_{O_2} = v_{H_2O} \times \frac{w_{H_2O}}{w_{O_2}}$$

4 The equation of state for oxygen

$$P_{O_2} v_{O_2} = R_{O_2} T$$

is combined with item 3 to yield

$$P_{O_2} = \left(\frac{w_{O_2}}{w_{H_2O}}\right) \frac{R_{O_2}T}{v_{H_2O}}$$

5 The total pressure of the decomposed products is

$$P = P_{H_2O} + P_{O_2}$$

6 The specific enthalpy of oxygen h_{O_2} is found from T and (6).

7 The specific enthalpy of the mixture is

$$h = h_{H_2O}\left(\frac{w_{H_2O}}{w_{H_2O} + w_{O_2}}\right) + h_{O_2}\left(\frac{w_{O_2}}{w_{O_2} + w_{H_2O}}\right)$$

8 The state point is located on the Mollier chart from T, P, h, and X.

II Procedure for Calculating Superheated Steam Region

1 Assume a value of temperature T and partial pressure of water P_{H_2O}.

2 From (10) find h_{H_2O} and v_{H_2O}. See comment on enthalpy base value under I, item 2.

3 Compute P_{O_2} from

$$P_{O_2} = \left(\frac{w_{O_2}}{w_{H_2O}}\right) \frac{R_{O_2}T}{v_{H_2O}}$$

(For further information see I, items 3 and 4.)

4 By addition $P = P_{H_2O} + P_{O_2}$.

5 From T and (6) find h_{O_2}.

6 By addition

$$h = h_{H_2O}\left(\frac{w_{H_2O}}{w_{H_2O} + w_{O_2}}\right) + h_{O_2}\left(\frac{w_{O_2}}{w_{O_2} + w_{H_2O}}\right)$$

7 The state point is plotted on the Mollier chart from T, P, and h.

III Check on the Pressure Lines of (1) as Used in the Construction of the Mollier Charts

Pressure lines were plotted as a function of enthalpy and entropy from data in (1). Temperature lines as a function of pressure and enthalpy were calculated as described in parts I and II of the Appendix and superimposed upon the pressure lines. The temperature line data were checked for agreement with the pressure lines by computing entropy as described below:

1 The following data for a particular point on the chart is known from the calculations for the temperature lines, that is

$$T, P_{O_2}, P_{H_2O}, \frac{w_{O_2}}{w_{O_2} + w_{H_2O}}, \frac{w_{H_2O}}{w_{H_2O} + w_{O_2}}$$

2 From (6) find s_{O_2} corresponding to T and 1 atm pressure. From perfect gas theory find the change in entropy from 1 atm to P_{O_2}; thus

$$\Delta s_{O_2} = R_{O_2} \ln \frac{P_{O_2}}{P_{1\text{ atm}}}$$

so that

$$s_{P_{O_2}, T} = s_{1\text{ atm}, T} - \Delta s_{O_2}$$

3 From (6) find s_{H_2O} corresponding to T and 1 atm pressure. From (10) find

$$\Delta s_{H_2O} = s_{H_2O\,(1\text{ atm}, T)} - s_{H_2O(P_{H_2O}, T)}$$

then

$$s_{H_2O(P_{H_2O}, T)} = s_{H_2O\,(1\text{ atm}, T)} - \Delta s_{H_2O}$$

4 The specific entropy of the mixture at T and P ($= P_{O_2} + P_{H_2O}$) becomes

$$s_{(H_2O+O_2)} = s_{O_2(P_{O_2}, T)}\left(\frac{w_{O_2}}{w_{O_2} + w_{H_2O}}\right) + s_{H_2O(P_{H_2O}, T)}\left(\frac{w_{H_2O}}{w_{H_2O} + w_{O_2}}\right)$$

5 The value of entropy computed above, $s_{(H_2O+O_2)}$, was checked against the value from (1), used to plot pressure lines, and found to be in close agreement.

References

1 Brinkley, S. R., Jr., Smith, R. W., Jr., and Edwards, H. E., "Performance Calculations of Hydrogen Peroxide as a Monopropellant (I Homogeneous Systems)," Bureau of Mines Report PX3-107/13, June 1953.

2 Brinkley, S. R., Jr., Smith, R. W., Jr., and Edwards, H. E., "Performance Calculations of Hydrogen Peroxide as a Monopropellant (II Heterogeneous Systems)," Bureau of Mines Report PX3-107/14, June 1953.

3 Brinkley, S. R., Jr., "Note on the Conditions of Equilibrium for Systems of Many Constituents," *Journal of Chemical Physics*, vol. 14, 1946, pp. 563–564, 686.

4 Kandiner, H. J., and Brinkley, S. R., Jr., "Calculations of Complex Equilibrium Relations," *Industrial and Engineering Chemistry*, vol. 42, 1950, pp. 850–855.

5 Beattie, J. A., "The Computation of the Thermodynamic Properties of Real Gases and Mixtures of Real Gases," *Chemical Reviews*, vol. 44, 1949, pp. 141–192.

6 "Selected Values of Chemical Thermodynamic Properties," Issued irregularly by the National Bureau of Standards.

7 "Hydrogen Peroxide Physical Properties Data Book," Buffalo Electro-Chemical Company, Inc., Buffalo, New York, 1949.

8 Keenan, J. H., and Kaye, J., "Gas Tables," John Wiley and Sons, New York, 1948, p. 238.

9 Weymouth, F. R., Bell Aircraft Corp., Meteor Report BAC-25, Feb. 1, 1950.

10 Keenan, J. H., and Keyes, F. G., "Thermodynamic Properties of Steam," John Wiley and Sons, New York, 1936.

Technical Notes

Significance of Quenching by Ports in Burning-Velocity Measurements by Bunsen Burner Methods[1]

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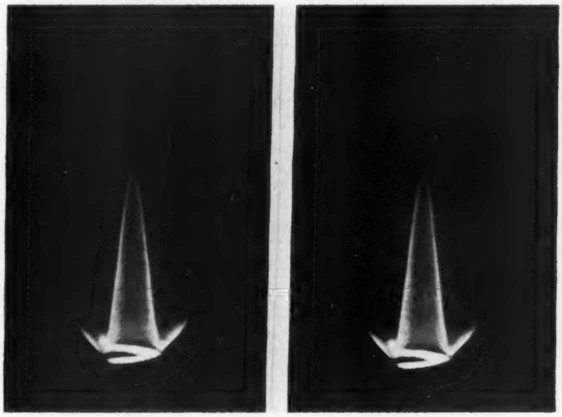
THIS note presents a new experiment pertaining to the role of flame port diameters in burning velocity measurements by burner methods. Other researchers have stated that low burning velocity values are obtained on ports smaller than a critical size determined by the mixture composition, pressure, and temperature (1, 2, 3, 4, 5).[4] A recent paper from this laboratory throws serious doubt on the accuracy of burner methods (6). A summary of that paper (7) has implied that we hold flame quenching at reduced pressures by ports to be insignificant. Rather, our viewpoint is that the effect of flame quenching by ports on burning velocities by the Bunsen burner method is frequently overestimated. Wohl (8) has pointed out that quenching in such measurements is unlikely over most of the flame, which is relatively far downstream and radially inward from the wall. We agree with Wohl and present the following experiment as substantiation. (Another mechanism, possibly that of flame cooling by the ambient atmosphere, should be considered to explain low burning velocities obtained on small port burners.)

Fig. 1 shows two photographs of an 0.8 stoichiometric methane-air flame stabilized by a 1.0-cm-diam coil of 1-mm-OD stainless steel tubing, with and without water cooling. The coil was hot in the latter instance. Both photographs are practically identical, showing the absence of major quenching over most of the flame by the port. The coil has been illuminated with a narrow beam of light to show the exact flame position with respect to it. A similar experiment with stoichiometric methane-air flames resulted in an increase in flame height of about 4 to 5 per cent when the glowing hot coil was water-cooled. The small increment in burning velocity indicated by the change in flame height may well be the consequence of preheat of unburned gas by the glowing hot coil.



(a) (b)

Fig. 1. 0.8 stoichiometric methane-air flames stabilized on tubing coil, (a) with coil water-cooled, (b) without cooling

Received Aug. 1, 1956.

[1] This research is a part of the work being carried out at the Bureau of Mines on Project NA onr 25-47, NR 098 117, supported by the Office of Naval Research through Project SQUID.

[2] Physical Chemist, Flame Research Section, Division of Explosives Technology.

[3] Physical Chemist, Chief, Flame Research Section, Division of Explosives Technology.

[4] Numbers in parentheses indicate References at end of paper.

References

1 Smith, F. A., and Pickering, S. F., "Measurement of Flame Velocity by a Modified Burner Method," *Journal of Research of the National Bureau of Standards*, vol. 17, July 1936, pp. 7–43.

2 Wohl, K., and Kapp, N., "Flame Stability at Variable Pressures," Meteor Report UAC-42, Oct. 1949.

3 Cullen, R. E., "A Nondimensional Correlation of Flame Propagation at Subatmospheric Pressures," *Trans. ASME*, vol. 75, 1953, pp. 43–47.

4 Singer, J. M., "Burning Velocity Measurements on Slot Burners; Comparison with Cylindrical Burner Determinations," Fourth Symposium (International) on Combustion, Williams and Wilkins, Baltimore, 1953, pp. 352–358. Also, unpublished data.

5 Gaydon, A. G., and Wolfhard, H. G., "Flames, Their Structure, Radiation and Temperature," Chapman and Hall, London, 1953, p. 75.

6 Singer, J. M., Grumer, J., and Cook, E. B., "Burning Velocities by the Bunsen-Burner Method. I. Hydrocarbon-Oxygen Mixtures at One Atmosphere. II. Hydrocarbon-Air Mixtures at Subatmospheric Pressures," Proceedings of the Gas Dynamics Symposium on Aerothermochemistry, Aug. 22–24, 1955, Northwestern University, 1956, pp. 139-150.

7 Weir, A., Jr., "Summary of Technical Sessions, Gas Dynamics Symposium," JET PROPULSION, vol. 25, 1955, pp. 553–556.

8 Wohl, K., "Discussion of 'A Nondimensional Correlation of Flame Propagation at Subatmospheric Pressures,'" *Trans. ASME*, vol. 75, 1953, pp. 48–49.

EDITOR'S NOTE: This section of JET PROPULSION is open to short manuscripts describing new developments or offering comments on papers previously published. Such manuscripts are published without editorial review, usually within two months of the date of receipt. Requirements as to style are the same as for regular contributions (see first page of this issue).

Heat Transfer and Friction Characteristics

(*Continued from page 984*)

could be used to predict the heat transfer characteristics provided that the surface was initially clean and the operating duration was less than 90 sec.

6 In the experiments with RFNA, scale or deposits formed almost immediately; in a run of 12-min duration at a heat flux density of approximately 1.8 Btu/sq in. sec and a Reynolds number of approximately 195,000, the j-modulus decreased 33 per cent. With a lower heat flux density and Reynolds number—0.6 Btu/sq in. sec and 113,000, respectively—the scaling was even more rapid and severe, reducing the Colburn j-modulus 55 per cent in only 7 min.

7 Isothermal friction coefficients were measured for WFNA over the range of Reynolds number from 38,000 to 450,000 and for RFNA over the range of Reynolds number from 45,000 to 140,000. In all cases the isothermal friction coefficients are approximately 20 per cent higher than those presented by L. F. Moody for smooth tubes (9).

8 Nonisothermal and isothermal friction factors for WFNA may be correlated satisfactorily by the equation

$$\frac{f_{iso}}{f_{non\text{-}iso}} = \left(\frac{\mu_b}{\mu_i}\right)^{0.12}$$

9 The nonisothermal friction coefficients for RFNA could not be correlated because of the scatter, attributed to surface roughness caused by the scaling.

Acknowledgments

The information presented in this paper was obtained at the Jet Propulsion Center, Purdue University, under Contract NA w-6286, a research program sponsored by the National Advisory Committee for Aeronautics. The authors wish to express their appreciation to M. J. Zucrow for his helpful guidance during the course of the investigations and to the personnel of the Jet Propulsion Center for their assistance in constructing and maintaining the apparatus.

References

1 Reese, B. A., and Graham, R. W., "Desgn of Apparatus for Determining Heat Transfer and Frictional Pressure Drop of Nitric Acid Flowing Through a Heated Tube," NACA RM 52D03, June 1952.

2 Reese, B. A., and Graham, R. W., "Experimental Investigation of Heat-Transfer and Fluid-Friction Characteristics of White Fuming Nitric Acid," NACA TN 3181, May 1954.

3 Reese, B. A., and Graham, R. W., "Heat Transfer and Frictional Pressure Drop Characteristics of White Fuming Nitric Acid," Jet Propulsion, vol. 24, July–Aug. 1954, p. 228.

4 Wolf, H., and Gray, F. L., "Experimental Investigation of the Heat Transfer and Fluid Friction Characteristics of White Fuming and Red Fuming Nitric Acid at High Heat Flux Densities," NACA Contract NAw-6286. Available as loan copy from NACA, Washington, D. C.

5 Ashley, E., "Heat Transfer Measurements for White Fuming Nitric Acid," Bell Aircraft Corporation, Report 56-982-016, Feb. 16, 1953.

6 Mason, D. M., and Taylor, L. L., "Inhibiting Effect of Hydrofluoric Acid in Fuming Nitric Acid on Liquid- and Gas-Phase Corrosion of Several Metals," Jet Propulsion Laboratory, California Institute of Technology, Progress Report 20-255, Jan. 24, 1955.

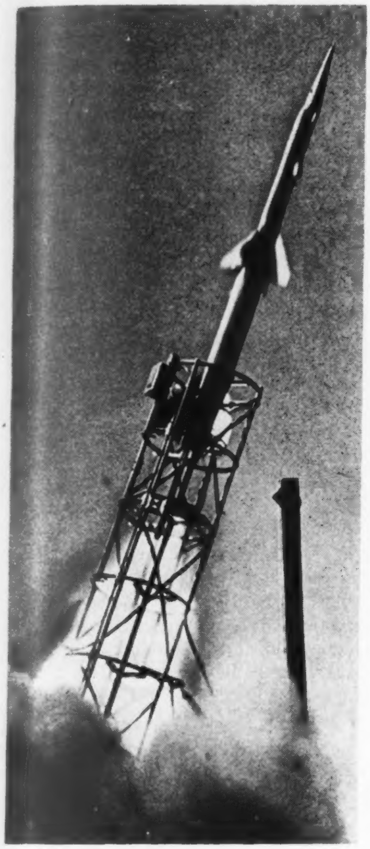
7 Sibbitt, W. L., St. Clair, C. R., Bump, T. R., Pagerey, P. F., Kern, J. P., and Fyfe, D. W., "Physical Properties of Concentrated Nitric Acid," NACA TN 2970, June 1953.

8 Mason, D. M., Petker, J., and Vango, S. P., "Viscosity and Density of the Nitric Acid-Nitrogen Dioxide-Water System," Jet Propulsion Laboratory, California Institute of Technology, Progress Report 20-214, 1954.

9 Moody, F. L., "Friction Factors for Pipe Flow," *Transactions of The American Society of Mechanical Engineers*, vol. 66, 1944, pp. 672–673.

Jet Propulsion News

Alfred J. Zaehringer, American Rocket Company, *Associate Editor*



Thermal Probe

DEVELOPMENT of a free flight USAF research rocket that reaches nearly seven times the speed of sound in just two seconds was recently revealed by Curtiss-Wright Corp. and Wright Air Development Center.

Designated HTV (Hypersonic Test Vehicle), the rocket is expected to be the precursor of a family of similar vehicles designed to gather data at hypersonic speeds. It is a two-stage solid propellant vehicle. The first stage is 5 ft long, 9 inches in diameter, and has three laminated glass fiber stabilizer fins. It consists of seven rockets which ignite simultaneously. When these burn out, the first stage falls away.

The second stage consists of four WASP I rockets. It is 5 ft long, 6 in. in diameter, has four laminated glass fiber stabilizer fins, and is topped with a 2-ft nose cone. The nose cone contains a magnetic tape recorder which charts such data as acceleration, temperatures, and pressures.

The HTV is launched from a 16-ft portable launcher. About 6 sec after the second-stage rockets burn out, the fins on the second stage are blown off by small charges within the vehicle causing the rocket to lose its stability and tumble to earth in a flat 100-mph spin.

Fifteen experimental HTV's have already been fired at ARDC's Holloman Air Development Center, Alamogordo, N. Mex. Development of the rocket was begun in 1953 by Aerophysics Development Corp. (which recently became a wholly owned subsidiary of Curtiss-Wright Corp.) in conjunction with WRDC's Wright Air Development Center.

Thermal Wedge

A NEW wedge in the thermal barrier might best describe National Carbon Co.'s new research laboratories in Parma, Ohio. Recently dedicated, the multimillion dollar laboratories will greatly expand parent company Union Carbide and Carbon Corp.'s research program in solid state physics (and closely allied chemical physics), electrochemistry, carbon and graphite research, and development of high-temperature processes and refractory compounds.

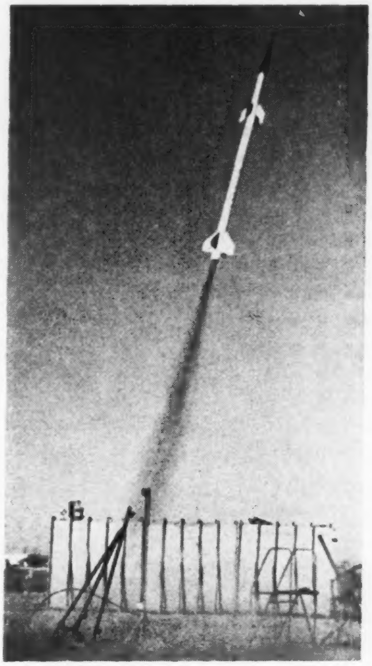
Of particular interest to the missile engineer will be the laboratories' research of refractory materials of construction such as carbon, carbides, nitrides, borides, etc. The labs, for example, are equipped with facilities for the simultaneous application of high temperature (to 4000 C) and high pressure (to 50,000 psi).

Extensive investigation is already underway on the properties of certain metal silicides that show promise as structural materials at temperatures above 1000 C. Goal is to find means of combining ductility and improved thermal shock resistance with the high-temperature strength of silicides, and to find new silicides with oxidation resistance comparable with that of molybdenum disilicide.

But this is only one aspect of the many-sided research program planned by National Carbon. Looking into the future, the company foresees the development of new materials for the metal, electronic, power, chemical, and electrochemical industries. And from these new materials, undoubtedly, will come the missile components for a thermal breakthrough.

MISSILES

REPUBLIC Aviation Corp. recently released details on a new two-stage high-altitude research rocket, the Terrapin (see photo). The vehicle is about 15 ft long and $6^1/_4$ in. wide; it weighs 224 lb and uses a collapsible zero-length launcher. On the maiden flight at Wallops Island, Va., the first-stage solid propellant rocket motor carried the Terrapin to 10,000 ft in 6 sec and separated. The vehicle rose to 30,000 ft and then the second-stage motor cut in, carrying it to 50,000 ft at a maximum speed of Mach 5.8. The Terrapin then coasted to a peak altitude of about 80 miles.



TERRAPIN: Low cost, high performance

The vehicle carried 6 lb of miniature instrumentation designed to record data on primary cosmic radiation, temperatures, acceleration, and rocket spin. At maximum velocity, reports Republic, the Terrapin experienced temperatures in excess of 1000 F. A third-stage rocket, now under development at Republic, is expected to push the vehicle to a peak altitude of 200 miles.

Taking its name from the University of Maryland mascot, the Terrapin is the first of "several dozen" research vehicles to be produced by Republic for a Department of Defense upper atmosphere research project being carried out by a group of University of Maryland scientists headed by S. Fred Singer.

Robert Melrose, general manager of Republic's Guided Missiles Div., described the Terrapin as one of the cheapest and most portable high performance rockets of its kind and said it cost only a fraction of earlier high-altitude vehicles.

• Reaction Motors, Inc., recently completed preparation of Viking powerplants for use in the flight test phase of Project Vanguard. A liquid propellant rocket with a rated thrust of 20,000 lb, the unit will power a modified Martin Viking missile which will carry aloft the Vanguard's third-stage solid rocket, first Vanguard propulsion unit to be tested. The flight test program will take place at the Air Force Missile Test Center near Cocoa, Fla., sometime before the launching of the actual satellite.

• Meanwhile, the first guidance reference system for the Project Vanguard vehicles has come off the pilot production line at Minneapolis-Honeywell Regulator Co.

• The Army was reported by various newspapers to have fired a test device hundreds of miles out over the Atlantic Ocean, from Patrick Air Force Base on Florida's east coast, in the first long-distance experiment of its Jupiter IRBM program.

• In a recent radio interview, Lt. General James M. Gavin, Army deputy chief of staff for research and development, said he considers the Nike the world's best surface-to-air missile, claimed it can destroy anything now flying in an operational unit. Gen. Gavin added planes may be replaced by missiles for close support of ground troops.

• A new surface-to-surface guided missile, Lacrosse, is now in production at Martin Co.'s Baltimore facilities. Developed by Cornell Aeronautical Laboratory under Army Ordnance contract, the missile is designed for close support operation on the battlefield. Launcher is mounted on a standard army truck.

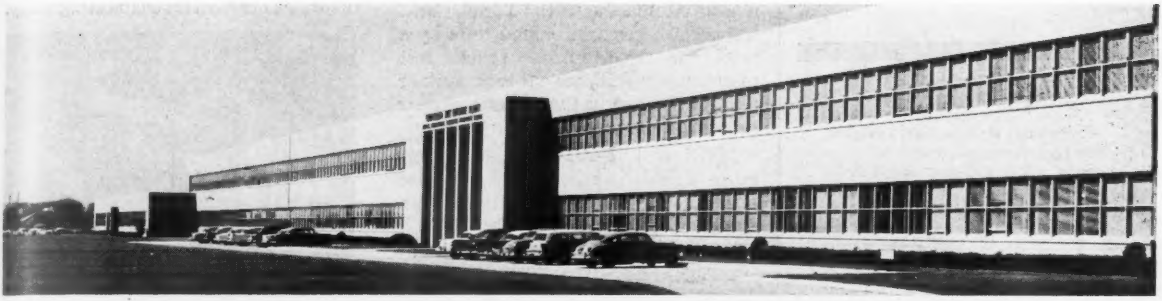
• Design speed of Triton missile, developed by Applied Physics Laboratory of Johns Hopkins University for Navy, is approximately Mach 2.5. Missile is about 45 ft long and 5 ft wide, weighs about 19,500 lb.

AIRCRAFT

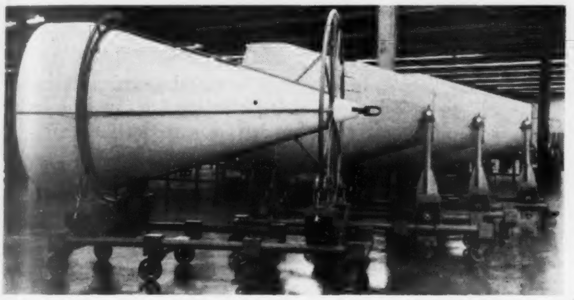
• Late in August, the rocket-powered Bell X-2, piloted by Capt. Iven Kincheloe, climbed to a record 126,000 ft. On Sept. 27, the experimental craft, piloted this time by Capt. Milburn Apt, crashed on its glide down after fuel burnout. Capt. Apt, on an indoctrination flight, was killed when the main parachute on his escape capsule failed to open.

• Another experimental airplane, the Douglas turbojet X-3, has been retired following almost four years of flight testing. The "flying stiletto," equipped with 1200 lb of specialized instruments, gathered valuable transonic and supersonic data used in the design of current jet fighters. Too, the X-3 project aided in the development of fabrication and construction techniques

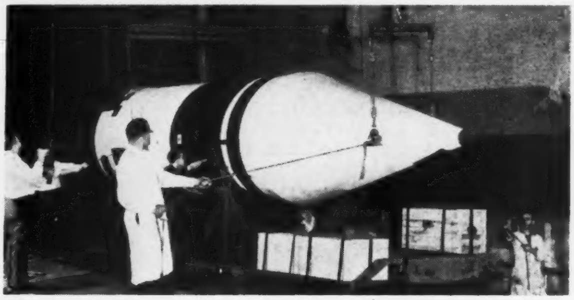
Chrysler Assembles the Redstone



REDSTONE PLANT, northeast of Detroit, was taken over by Chrysler when it entered Army project as prime contractor in 1952.

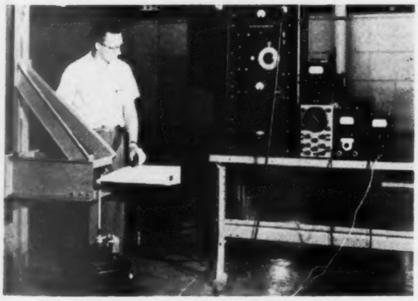


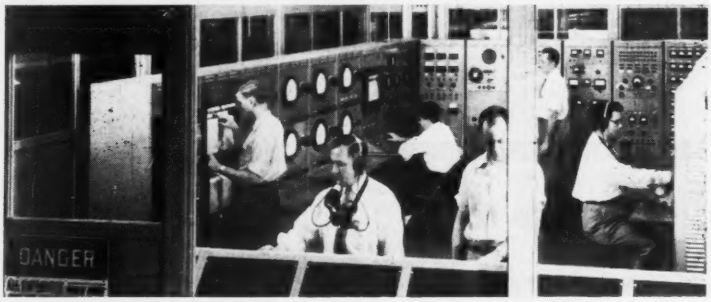
MISSILE NOSE cones are shown here ready for final assembly.



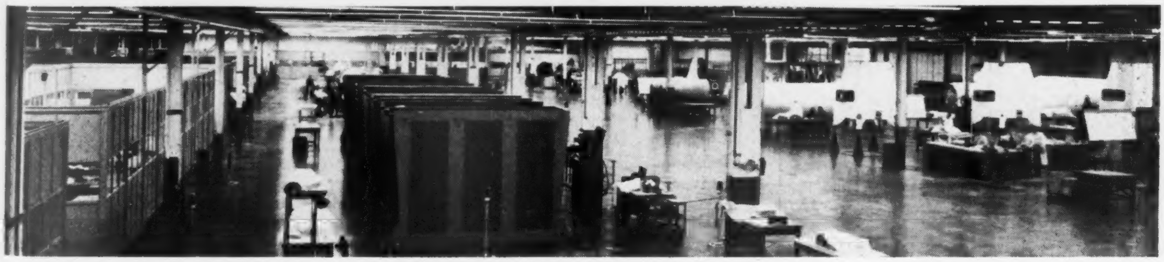
COMPLETED WARHEAD is moved down line by 5-ton crane.

FINISHED MISSILE, reportedly powered by North American LOX rocket engine of 65,000-lb thrust, has 200–300 mi range.





CHECK-OUT: Air vane assembly (left) is vibrated at 5–2000 cps, forces up to 40 g. Engineers (right) record data as . . .



. . . flight of surface-to-surface ballistic missile is simulated inside wire shelter before 60-ft Redstone is disassembled for shipment.

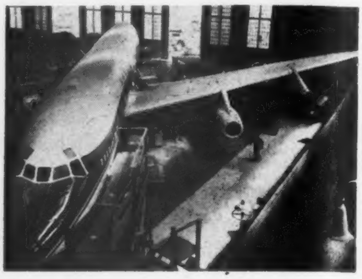
for titanium which was used extensively throughout the aircraft.

• A turbojet engine "of the type now used extensively in military aircraft," reports Atomic Industrial Forum, Inc., has been powered in ground tests by a reactor at Arco, Idaho. Fifteen test reactors, says AIF, are either at work or planned for use in the aircraft nuclear propulsion program.

• McDonnell F-101A Voodoo long-range fighter is scheduled to go into operational service early next year. Another McDonnell craft, the F3H-2N Demon, displays its two external fuel tanks and four interceptor rocket packages in an unusual photo below.

• North American FJ-3 Furies are being used as chase aircraft for Regulus missiles at Navy's Chincoteague (Va.) missile testing grounds.

• Production of Douglas DC-8 jet transport moved forward recently with the milling of the first spar cap for the craft's wing. Meanwhile, the wooden mock-up (see photo) of the transport continues to serve as a valuable three-dimensional model for engineering study.



• Douglas' twin-jet light bomber, the Destroyer, has been officially designated the B-66 by the Air Force.

GOVERNMENT

• The first comprehensive account of Federal organization for scientific activities since 1947 was recently released by National Science Foundation. The report is titled "Organization of the Federal Government for Scientific Activities" and may be purchased from Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., for $1.75.

• Thomas Wolfe of Pasadena, Calif., is the new Director for Requirements, Procurement and Distribution in the Office of Assistant Secretary of Defense (Supply and Logistics).

• Air Force is stepping up production of KC-135 jet tankers, hopes to hit rate of 20 per month shortly.

Made in Japan

Preparing for participation in the upcoming IGY program, a team of Japanese scientists headed by Tokyo University's Hideo Itokawa (center, shading eyes) recently test-fired a new supersonic rocket.

Designated Kappa 128 JT, the rocket is a prototype of the vehicle that the Japanese plan to use as the main stage of their proposed two- and three-stage IGY rockets. The Kappa weighs 40 kilograms, has a 72-sec flying time, and is said to be capable of reaching Mach 2.7.

Now from Clary!

A new kind of solenoid valve for guided missiles

America's smallest, lightest, most reliable solenoid valve.

Controls air, helium, nitrogen, LOX or corrosive liquids.

Below, standard 1/8" valve with Bendix connector 10-63212-3P.

EXCLUSIVE FEATURES

Zero leakage. Internal vent to atmosphere through *controlled outlet* prevents drawing moisture-laden or contaminated air into cavity of moving parts. *Hermetically-sealed coil* assures trouble-proof operation. Solenoid may be rotated on valve body to place electrical connector in most desirable location. This same Clary valve can be used for *"normally open"* or *"normally closed"* service by simple mechanical rearrangement of the solenoid.

STANDARD VALVES*

Rated Operating Pressure: 3000 PSI
Voltage: 18-30 D.C.
Connector: Bendix 10-63212-3P
Packing: AN "O" Rings

Tube Size	Service	Part No. Normally Closed	Part No. Normally Open
DIRECT-OPERATED			
1/8"	2-way	520030	520031
1/8"	3-way	520032	520033
1/4"	2-way	520034	520035
1/4"	3-way	520036	520037
3/8"	2-way	520038	520039
3/8"	3-way	520040	520041
PILOT-OPERATED			
1/2"	2-way	520042	520043
1/2"	3-way	520044	520045
3/4"	2-way	520046	520047
3/4"	3-way	520048	520049

*Modifications available to meet design requirements.

We are proud to announce a new complete line of solenoid valves to meet the most stringent environmental conditions encountered by guided missiles. Our years of experience in manufacturing guided missile components – gyroscopes, servo-actuators, propellant valves, telemetering transducers – now enable us to bring you solenoid valves built with the same precision. Our extensive inspection and quality control guarantee the maximum reliability required of missile components.

Clary AUTOMATIC CONTROLS DIVISION

Clary Corporation, Dept. J116, San Gabriel, California

MANUFACTURER OF BUSINESS MACHINES, ELECTRONIC DATA-HANDLING EQUIPMENT, AIRCRAFT AND MISSILE COMPONENTS

• As part of its Standardization Program, Department of Defense has published a Directory of FSC (Federal Supply Classification). The new Directory assigns by number and title each specific commodity area to a cognizant military department, is available to all military contractors.

• Navy recently presented Distinguished Public Service Award to John B. Hawley, Jr., president, and Garold A. Hane, executive vice-president, of Northern Ordnance, Inc. (Minneapolis), a plant credited by the Navy with development and production of the world's first automatic stowage, handling, and launching system for guided missiles carried on board ships. The system is now installed on USS Boston and USS Canaberra to launch Terrier missiles.

• Government has awarded a $1.7-million contract to newly formed Institute for Defense Analyses to perform studies and prepare reports (on, among other things, effectiveness of various weapons systems) as directed by Weapons System Evaluation Group headed by Lt. General B. E. Anderson, USAF.

COMPANIES

• Norden-Ketay Corp., manufacturer of precision control instrumentation and systems, is moving its executive offices to Stamford, Conn., where it will also establish a central research laboratory for missile work. The firm recently reported new missile work in excess of $5 million.

• Westinghouse Electric Corp. (Pittsburgh, Pa.) has been awarded an $18,335,305 government contract to furnish reactor compartment components for a nuclear-powered guided missile light cruiser (CLGN).

• Garrett Corp.'s AiResearch Manufacturing Division (Los Angeles) will furnish air conditioning and pressurization systems for Boeing 707 jet airliners.

• Kollsman Instrument Corp. (Elmhurst, N. Y.), manufacturer of flight control and navigation instruments and systems, expects its $35-million order backlog to top $50 million by end of the year.

• Aeronautical Div. of Minneapolis-Honeywell Regulator Co. will supply transistorized fuel-measuring systems for Lockheed Electra and Boeing 707 transports.

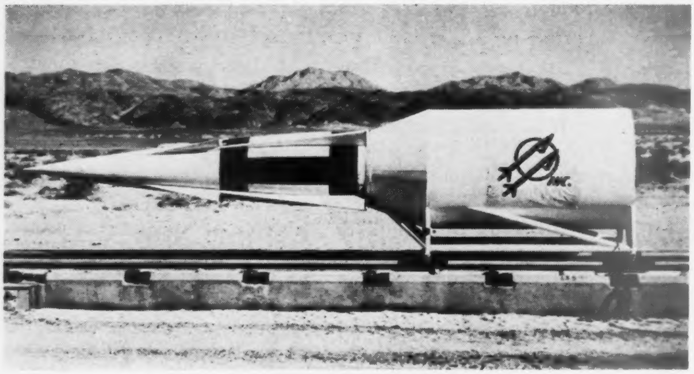
• ACF Industries, Inc., has established a Missiles Group to coordinate the activities of its many divisions in the field of missiles and related weapons systems. Richard F. Wehrlin, president of ACF's Avion Division, was named chairman.

• Titanium Fabricators, Inc. (Burbank, Calif.), has received a $196,000 contract from Convair Div. of General Dynamics Corp. to produce machined titanium parts for Convair's delta-wing, supersonic F-106A.

• Stauffer Chemical Co. will build a major titanium tetrachloride plant at Ashtabula, Ohio, to supply raw material for National Distillers Corp.'s new titanium sponge plant slated for that area.

• National Electronics Corp. (Los Angeles), maker of miniature electric motors, transformers, and electrical heating elements for missiles, has opened a third plant, in North Hollywood.

• Cooper Development Corp. (Monrovia, Calif.), developer of rocket and missile systems, is planning a major facility expansion, says the firm, to accommodate demands for its ASP and WASP rocket vehicle systems and increased research and development activities.



Ground Gainer

In recent tests at Naval Ordnance Test Station (China Lake, Calif.), Aircraft Armaments, Inc. (Baltimore), rocket sled hit 1300 mph in under 2.5 sec. Power came from three solid propellant rocket motors.


MACH TRANSDUCER
with range of
0.1 to 3.0 Mach
TOTAL TEMP. TRANSDUCER
for altitudes to 80,000 ft., temps.
SENSITIVE ALTITUDE TRANSDUCER
AIRSTREAM DIRECTION TRANSDUCER
with accuracy of 0.1 degree
90 knots to supersonic
ABSOLUTE AND DIFFERENTIAL
PRESSURE TYPE TRANSDUCERS
with accuracy to 0.4%
CENTRAL COMPUTER
containing all necessary
system mechanization of
both electronic and
mechanical types
PLUG-IN AMPLIFIER MODULE
utilizing either vacuum
tube, mag-amp
or transistor
ACCELEROMETER
with accuracy to 0.4% of G
ENGINE PRESSURE RATIO INDICATING SYSTEM
with accuracy of 0.02 ratio units
HIGHLY-EFFICIENT ACTUATORS
to provide mechanical outputs

FOREIGN

Australia: QUANTAS Empire Airways, Ltd., has ordered seven Boeing 707 jet airliners. Delivery is scheduled to start May 1959.

England: On Sept. 17, the first American Corporal missile arrived in Britain for training and operational use. It is expected that guided missile units equipped with the Corporal will eventually join Britain's Army of the Rhine.

• First Fairey Fireflash guided missiles are scheduled to reach RAF squadrons next month. They will serve as training, not operational, weapons because there reportedly is a better air-to-air missile on its way.

• Fighter Command Chief, Sir William Pike, was thought to be referring to the Saunders-Roe SR53 jet- and rocket-powered interceptor when he recently forecast the development of a fighter with a speed three times that of sound.

• Bristol Aero-Engines recently revealed that its Olympus B01.6 has an "officially attributed" thrust of 16,000 lb without reheat—the highest power yet announced for any British jet engine. They are now in quantity production for the four-jet Avro Vulcan bomber.

France: Air France has ordered 13 Lear advanced automatic flight control systems for its Caravelle jet transports.

Germany: On Sept. 5, Dr. Haas, West German Ambassador in Moscow, delivered a strong note protesting Russia's refusal to permit his government to communicate with German missile technicians working in Russia. The note accused Russia of denying internationally recognized consular rights, of breaking the Soviet-West German agreement on exchange of ambassadors, and of violating the U. N. Charter. Haas said the contracts under which the men (believed to number 45) had been working at Sukhumi, on the Black Sea, had expired and several of the men wanted to return home.

When asked about this matter previously by British correspondent (*Daily Telegraph*) Leonard Bertin, Leonid Sedov, head of the Russian Academy of Sciences' committee on interplanetary flight and high altitude research, replied that to his personal knowledge there were no German scientists of graduate status working on rocket projects in Russia any more. It was not good sense, he said, to employ Germans on jobs that the Russians could do themselves.

Pursuing the matter further, Mr. Bertin was told by Dr. Tromsdorf, one of Germany's top ramjet theoreticians who had worked under contract with the Russians, that he did not know what

IMPORTANT DEVELOPMENTS AT JPL

Pioneers in Guidance Systems

The Jet Propulsion Laboratory is a stable research and development center located to the north of Pasadena in the foothills of the San Gabriel mountains. Covering an area of 80 acres and employing 1550 people, it is close to attractive residential areas.

The Laboratory is staffed by the California Institute of Technology and develops its many projects in basic research under contract with the U. S. Gov't.

Qualified personnel employment inquiries now invited.

For many years the Jet Propulsion Laboratory has pioneered in the design and development of highly accurate missile guidance systems, utilizing the most advanced types of gyroscopes, accelerometers and other precision electro-mechanical devices. These supply the reference information necessary to achieve the hitherto unattainable target accuracies sought today.

The eminent success of the early "Corporal" missile flights shortly after World War II firmly established the Laboratory as a leader in the field of missile guidance. These flights also initiated experiments involving both inertial and radio-command systems employing new concepts of radar communication. Because of this research and experimentation JPL has been able to add materially to the fund of knowledge available to designers of complex missile systems.

This development activity is supported by basic research in all phases of electronics, including microwaves and antennas, new circuit elements, communications and reliability in addition to other branches of science necessary to maintain a fully integrated missile research organization.

The Jet Propulsion Laboratory, therefore, provides many challenging opportunities to creative engineers wishing to actively apply their abilities to the vital technical problems that require immediate and future solution.

We want to hear from men of proven ability. If you are interested please send us your qualifications now.

JOB OPPORTUNITIES IN THESE FIELDS NOW

jpl

INSTRUMENTATION • APPLIED PHYSICS • DATA HANDLING • COMPUTERS
TELEMETERING • RADIO AND INERTIAL GUIDANCE • GUIDANCE ANALYSIS
SYSTEMS ANALYSIS • MICROWAVES • ELECTRO-MECHANICAL • PACKAGING
MECHANICAL ENGINEERING

JET PROPULSION LABORATORY

A DIVISION OF CALIFORNIA INSTITUTE OF TECHNOLOGY

PASADENA • CALIFORNIA

other Germans were left in Russia because groups were segregated. They (the Germans) were consulted only on specific and isolated problems, never were told the whole story nor the names of others who were working on the same or related problems elsewhere.

Switzerland: Swissair recently placed its order for a third DC-8 jet airliner. Delivery is due in 1961.

RESEARCH & DEVELOPMENT

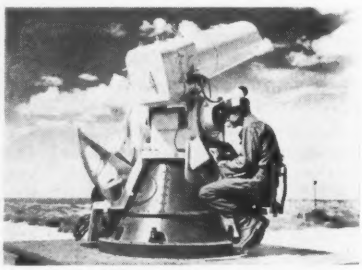
High Temperature Report

Proceedings of the three-day high temperature symposium held at the University of California last June are now in print and may be obtained from Public Relations Dept., Stanford Research Institute, Menlo Park, Calif. Cost: $5 per copy.

Titled "High Temperature—A Tool for the Future," the symposium was sponsored by Stanford Research Institute and University of California. Of the 600 registrants, most were from the U. S.; the rest, from several different countries abroad.

The subjects were treated in three major categories: methods for reaching high temperatures; materials for containing high temperatures; processes occurring at high temperatures. To further pinpoint the discussion, each of the three major divisions was then divided into three areas for discussion by separate panels. Thus, almost every aspect of high temperature research was covered in the 36 papers and panel discussions.

A featured luncheon address by Theodore von Kármán, chairman of the NATO Advisory Group for Aeronautical Research and Development, dealt with the subject "Aerodynamic Heating—Temperature Barrier in Aeronautics."



Missile Watcher

Army Signal Corps has developed a $1\frac{1}{2}$-ton telescopic tracker capable of tracing a missile 300 miles away. Now under test at White Sands Proving Grounds, the unit has a 400-lb lens system developed by Fairchild Camera and Instrument Corp., can automatically take black and white photographs of rockets, jets, and other flying objects.

• Another human engineering study is taking place at Ryan Aeronautical Co., under USAF contract, to determine optimum cockpit arrangement and instrument display requirements of VTOL aircraft.

• American Machine & Foundry Co.'s Turbo Division recently dedicated its new 66,000 sq ft advanced research and development center at Pacoima, Calif. The new center will be used for development of accessory power supplies for guided missiles.

• First International Ozone Conference is scheduled for Nov. 28–30 at Sheraton Hotel, Chicago. Sponsor is Armour Research Foundation in cooperation with a number of companies including Aerojet-General Corp.

• Scientists at Northrup Aircraft, Inc. (Hawthorne, Calif.), are researching the limits of human mental and physical abilities to command supersonic aircraft.

• Republic Aviation Corp. (New York) has subcontracted major missile and aircraft control problems to Systems Laboratories Corp. (Los Angeles).

• Marvelco Electronics Div. of National Aircraft Corp. is establishing an advanced electronic research and development center in San Diego.

• Thompson Products, Inc. (Cleveland), recently dedicated a new laboratory which will enable the company to test turbojet engine parts and assemblies of thrust ratings to 40,000 lb.

• National Science Foundation has selected Green Bank, W. Va., as the site for its new radio astronomy facility.

• General Electric's Aeronautic and Ordnance Dept., under sponsorship of Army Ordnance and with technical assists from Springfield (Mass.) Armory and Armour Research Foundation, has developed a new rapid-firing 20-mm cannon designed specifically for supersonic jet aircraft. Named Vulcan, the weapon is now being flight tested by the Air Force.

• Powder Metals Div. of Kwikset Locks, Inc. (Anaheim, Calif.), has installed what is claimed to be the first high temperature atmosphere-controlled furnace capable of reaching 3100 F, in the Southern California industrial region.

• Association for Applied Solar Energy in conjunction with Stanford Research Institute, Arizona State College at Tempe and University of Arizona will sponsor a two-day symposium on solar furnace design and operation, Jan. 21–22, 1957, Hotel Westward Ho, Phoenix, Ariz. Titled "Today's Tool for Tomorrow's Research," the symposium will deal with problems related to high temperatures, such as thermal shock, materials for missiles, etc.

• Under an Army Ordnance contract, Battelle Memorial Institute (Columbus, Ohio) has started research on erosion-resistant materials for nozzles of a rapid-fire antiaircraft rocket.

• American Machine & Foundry Co. in association with the ARDC Aero Medical Laboratory has developed a new instrument, the Period Analyzer (see photo), which interprets information presented by an electroencephalograph. Air Force interest in the instrument centers on its possible ability objectively to assess alertness level in pilots of high speed aircraft.

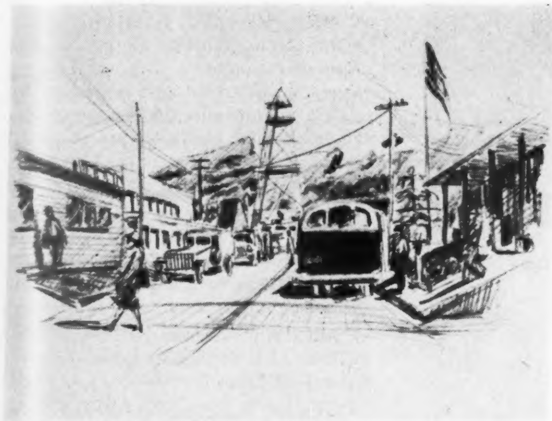
Anti-Gravity Machines? Not Yet

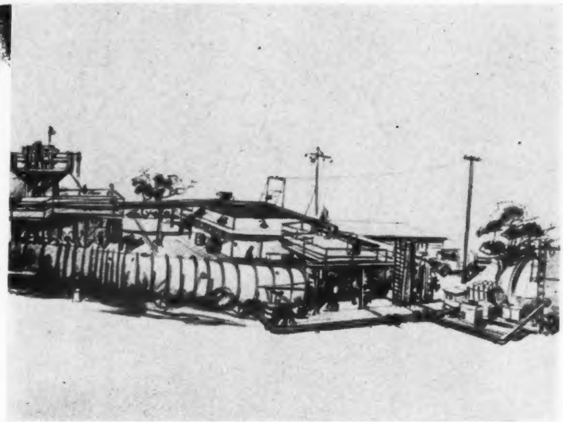
Rumors to the contrary, it will be a long time before anyone spots "anti-gravity" or "electro-gravitic" devices hovering in the air. True, a number of groups throughout the world are seriously working on Einstein's General Theory of Relativity, but no one has yet figured out a way to nullify the law of gravity—to say nothing of developing a "flying device" which would work on such principles.

In fact, says Welcome Bender of Glenn L. Martin's Research Institute for Advanced Studies, most groups are engaged in this work not with an eye to application but simply to develop a better understanding of Nature's gravitational laws on a basic research level. Likening present research on gravity to the early work on electricity, Mr. Bender said, "First we must get to know natural phenomena, then we learn how to live with it."

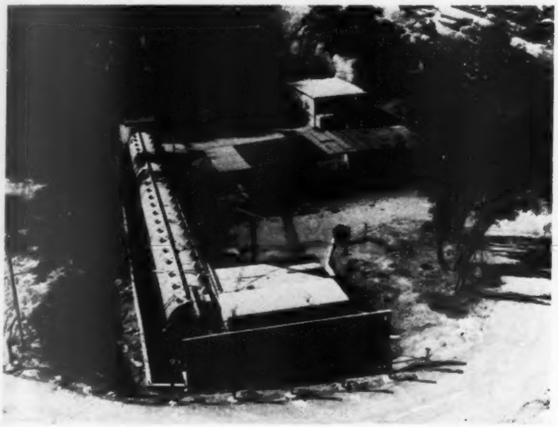
This is not to deny the possible development of practical applications from these studies. But at this stage, declares Mr. Bender, the problem still is much too formidable to conceive of practical applications such as anti-gravity flying devices.

Santa Susana Sketches



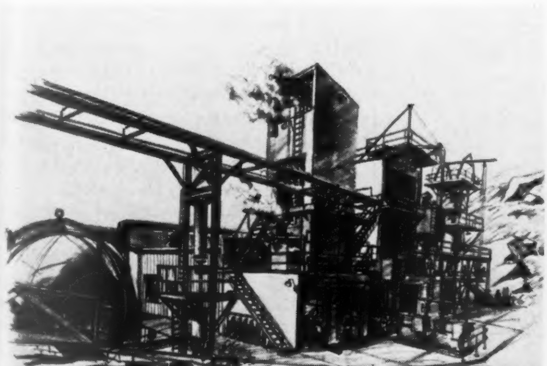


MAIN STREET (left) of North American Aviation's Propulsion Field Test Laboratory is depicted by artist. Located in the Santa Susana Mountains, about 35 miles from Los Angeles, the facility covers 1700 acres, serves as a test site for high-power rocket engines. IRBM and ICBM engines will be tested here. Unit (right) is where new liquid propellants are investigated.



FREE-FLIGHT duct (left) serves as test site for solid rockets. It is 100 feet long and 8 feet in diameter. Rockets—mainly of air-to-air variety—blast down duct in about 0.3 second.

Inside the duct (right) are a launching table, a bank of camera ports along the wall, and a flat chunk of 2-inch armor plate at the target end.



COMPONENTS LABORATORY (left): Here, pumps, regulators, and generators for high-thrust rocket enignes are put through their paces. But the big show comes from the bank of large static test stands (right), where large engines are tested one at a time. (Unusual photo is a composite, covers four-hour span of night firings.)

• Greer Hydraulics, Inc., has established a new R&D division to provide designs and prototypes for jet airliner airframes, engines, missiles, etc., on a systems basis.

• Surface Combustion Corp.'s Janitrol Aircraft-Automotive Div. is building a new development test laboratory for simulating altitudes and accompanying environmental conditions up to 80,000 ft. Lab will be located in Columbus, Ohio.

• Complete details of Lockheed's method of recording and analyzing guided missile flight, says the company, will be open to scientists of friendly nations.

• American Machine & Foundry Co. will build a $4-million R&D center in Stamford, Conn.

• Original RATO cost for B-47 was $450 each. Cost is now $160 each. Fully loaded B-47 requires 30 for take-off.

Define Your Terms, Please

Propellent vs. Propellant

THE fields of jet propulsion and rocketry, like many other scientific studies, have made their inroads into the English language. A point of some interest, perhaps, to the grammatically inclined scientist is the formal distinction in usage between the words *propellent* and *propellant*.

Simply taken, according to the twenty-five pound Webster, the *-ent* form may assume both the adjectival and the noun functions, whereas the *-ant* form has only the noun function. It must be emphasized that the adjectival usage of the *-ent* form refers to the propulsion, propelling, or motion produced by the propellent or propellant. The nouns refer only to the propelling materials themselves. This distinction is, at times, not followed with the result that the more frequently used *-ant* form is adapted fairly indiscriminately.

Is it incorrect to use *propellant* as an adjective, say in a phrase such as "the propellant effect of liquid oxygen-JP 4"? Our English Department would call preferred or conservative usage the application of the *-ent* ending if what is meant is the movement induced by this fuel combination. It appears then that universal adoption of *propellent* rather than *propellant* would keep us all safely within the bounds of grammatical propriety. However, as is likely, convention, as governed by the advances of science and the language used in reporting them, will undoubtedly bury another point already dead but in the dictionaries.

MEYER M. MARKOWITZ
College of Engineering
New York University

To Fly or to Sply?

THE word *fly*, and its noun form *flight*, is currently used to refer to motion away from and above the surface of the earth. Webster limits its meaning to an air environment; motion supported by, or through, the air is the essence of the generally accepted definition. As the bulk of serious nonfiction on man-generated movement through space swells in volume, it becomes important to modify its meaning.

However, expanding the meaning of *fly* is not as simple as it appears. We can't say *to fly is to move in a path that does not touch any part of the earth's surface* without the core of meaning being destroyed: Man has always thought of flight as movement independent of a stationary earth. Only since the advent of high speeds has the relative concept of motion, with nonterrestrial reference points, been considered. A rocket plane at the equator flying westward at 1000 mph is standing still, and the earth spins around it; the sun and stars, to an observer on the plane, stand still. If this view of *standing still* is accepted, the peculiar essence of the word is lost.

As further demonstration of the inadequacy of *to fly* as a universal term, consider the following: A planetoid traveling past the earth at 10,000 mph would be said by an observer on the earth to fly past. However, an observer on an imaginary planet close to the orbit of the earth which stood still relative to the sun would reach an entirely different conclusion. Since the earth would move past him at some 66,000 mph he would certainly say that the earth flew. Would either use of the word be correct, or neither?

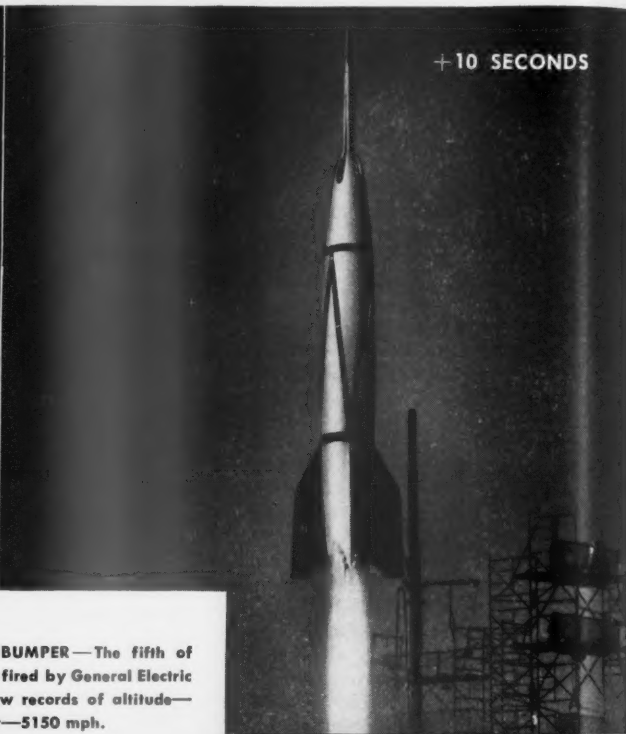
A solution to the problem would be to coin a new verb meaning *to move through a path not parallel to one generally described by a reference point on the surface of the earth.* The noun form would mean *nonterrestrially referred motion. Sply* (space fly) and *splight*, for example, would be specific in describing the motion of the westbound rocket, the planetoid, and the earth. Clearly, the thought conveyed by these words should be completed by adding a reference phrase, such as *from earth, from moon*, etc. If these nonterrestrially referred words were accepted, *fly* would retain its dictionary definition.

It may be impractical to initiate this discussion at the present time. But when our perspective changes, as we have reason to believe it will within ten years, we should have a word to say what we mean.

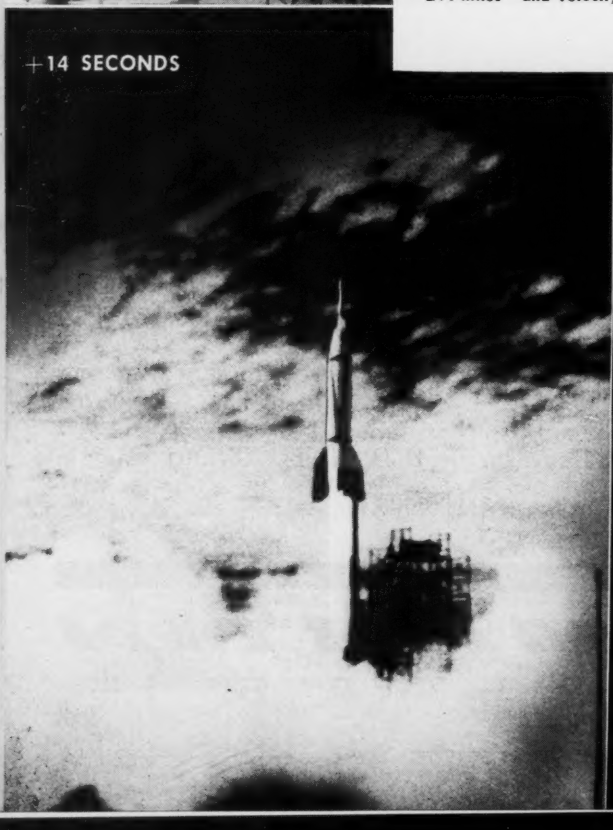
DAVID GREENFIELD[1]

[1] Suite 102, 6399 Wilshire Blvd., Los Angeles 48, Calif.

How General Electric Experience



1949—PROJECT BUMPER—The fifth of these two-stage rockets, fired by General Electric in 1949, established new records of altitude—244 miles—and velocity—5150 mph.



Advances Missile Technology

General Electric's Project Bumper established new records of altitude and velocity. But far more important is the valuable research data compiled in the successful completion of the Bumper project. Many problems were overcome with Bumper—problems in temperature, telemetry, separation, and aerodynamics. Bumper helped solve the problems of communicating with missiles at extreme altitudes, and was a major preliminary step in the development of a satellite. In solving these and other problems, General Electric has contributed a wealth of research data to the missile industry—information that is being utilized on the nation's top priority ballistic missile project.

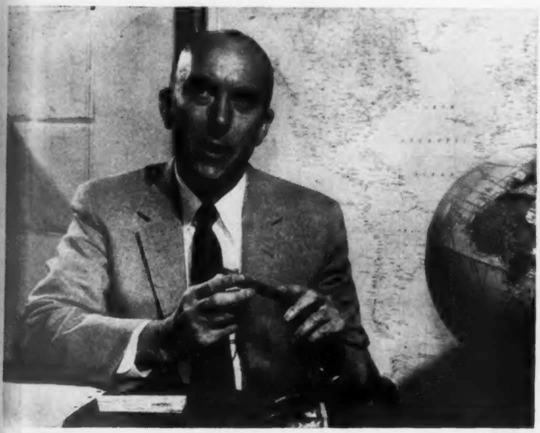
General Electric's Special Defense Projects Department presently is working on an Air Force prime contract to develop the ICBM nose cone. Programs are being carried out in such varied fields as communications, hypersonics, metallurgy, mathematics, and thermodynamics to support this nose cone contract.

General Electric has formed the Special Defense Projects Department to act as a Company focal point for large, highly complex missile projects. Scientists in the new department, backed up by the vast resources of many General Electric operating departments and laboratories, are currently working to solve the perplexing problems associated with the ICBM nose cone and other missile projects.

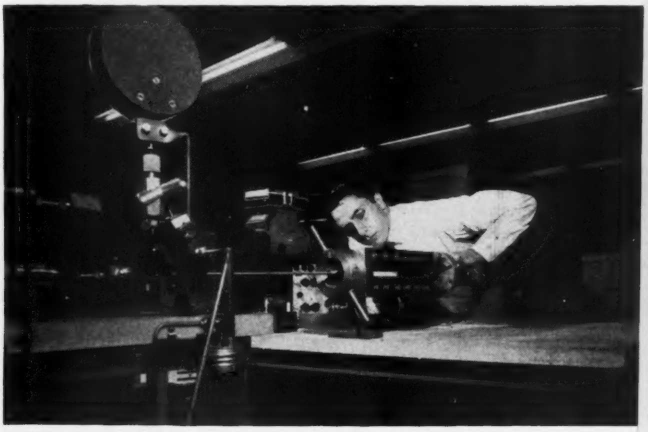
By focusing this wide range of specialized talents of General Electric personnel on highly complex defense system problems, the Special Defense Projects Department is making significant contributions to America's defense program. Section 224-5, General Electric Co., Schenectady 5, N. Y.

ENGINEERS: G.E.'s Special Defense Projects Department is currently expanding its staff of highly skilled engineers and scientists. If you have a background of successful creative engineering, send your qualifications to: Mr. George Metcalf, General Manager, Special Defense Projects Department, General Electric Co., 3198 Chestnut St., Philadelphia, Pa.

TODAY—**CONTINUED RESEARCH AND EXPERIMENTATION in advanced missiles and missile systems is helping solve such advanced problems as development of the ICBM nose cone. Headquarters for General Electric's participation in these programs is the Special Defense Projects Department in Philadelphia, Pa.**



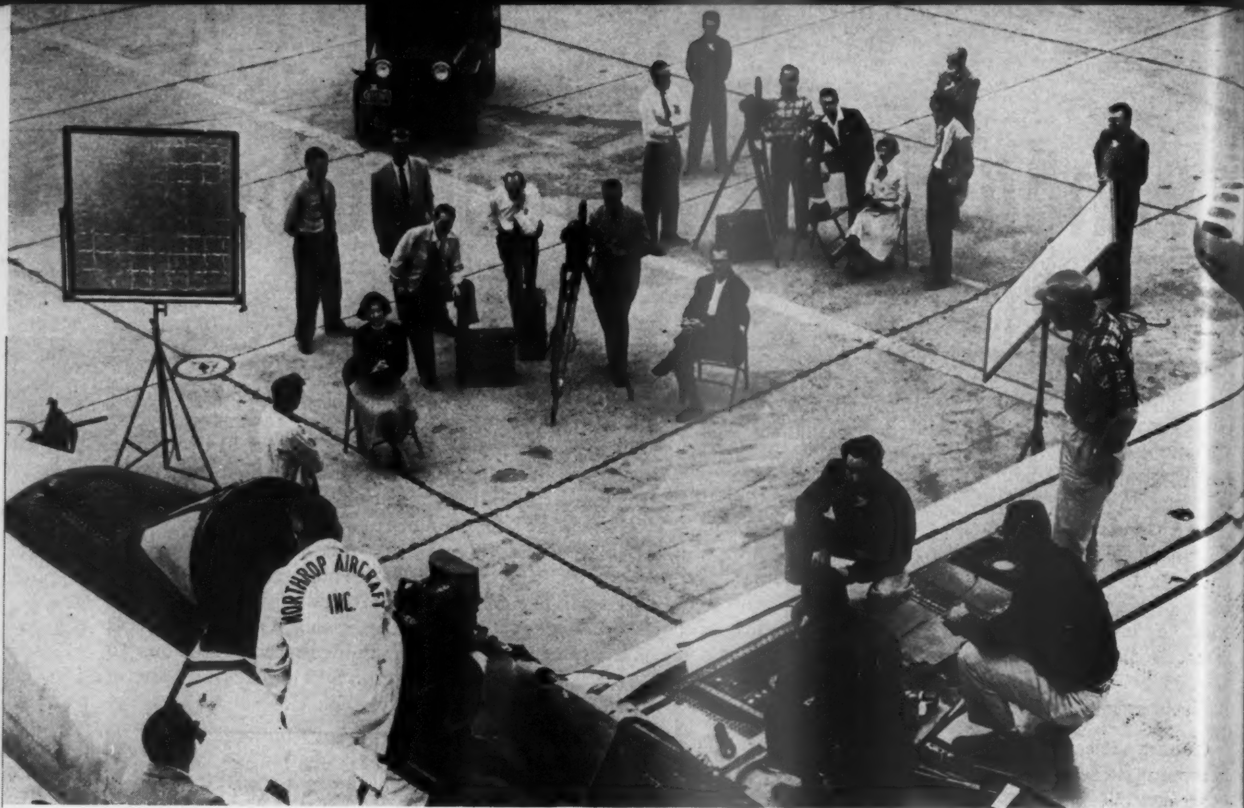
MR. ROBERT P. HAVILAND, Flight Test Engineer at SDPD, directed Project Bumper and other advanced programs, gaining valuable experience which he is currently applying to present missile programs.



DR. YUSUF A. YOLER—widely known for research in hypersonics—is currently engaged in the design and development of wind tunnels, shock tunnels, mass accelerators, and other facilities for continued progress in missile systems.

Progress Is Our Most Important Product

GENERAL ELECTRIC



Manufacturer's Twenty Member Motion Picture Unit sets up to shoot Northrop F-89D all-weather jet interceptor for sequences in Northrop Training Department film.

INDUSTRY'S USE OF 16MM CAMERAS BROADENS

Northrop Aircraft Demonstrates Expanded Industrial Use of Mitchell Cameras

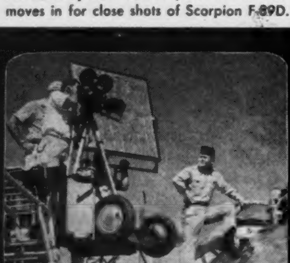
Over 100,000 feet of film were shot last year by two 16mm Mitchell cameras operated by a full-scale motion picture unit at Northrop Aircraft. Operating daily throughout the year, these 16mm cameras provide impressive evidence of the rising role of professional motion picture equipment in American Industry today.

Northrop, a leader in airframe and missile manufacture, makes diversified use of their Mitchell cameras. Motion pictures range from employee activities to engineering test films—where re-shooting is impossible and where steady, accurately-framed film of superior quality is consistently delivered by Mitchell cameras.

No other single camera is today used by American Industry for such a broad range of filming requirements as is the Mitchell camera. Easy operating Mitchell cameras help create sales, meet delivery schedules, and systematize and accelerate research and development. For details about Mitchell equipment that will meet your specific needs, write today on your letterhead.

Alaska Bound test pilot Bob Love and Columnist Marvin Miles being filmed by Mitchell camera for Northrop Public Relations Department.

For Quality Control Film, Mitchell camera moves in for close shots of Scorpion F-89D.



104 Rocket Salvo of twin-jet F-89D is captured on 16mm Engineering Test film.

Mitchell Camera
CORPORATION

666 WEST HARVARD STREET
GLENDALE 4, CALIFORNIA

Cable Address: "MITCAMCO"

***85% of professional motion pictures shown in theatres throughout the world are filmed with a Mitchell**

ARS Fall Meeting Turns Buffalo into . . .

Nation's Temporary Missile Capital

WITH a big assist from the Niagara Frontier host Section, another national meeting got off to a fast start and drew to a successful conclusion recently in Buffalo, N. Y. For a brief and busy time (Sept. 24, 25, 26), Buffalo was host to about 300 missile men and hub of the nation's missile information lines.

Registrants attended a special showing of Warner Brother's new film "Toward the Unknown" (about the Bell X-2), witnessed the premier of the documentary "Flight to the Future" (also about the X-2). At the technical sessions, they were given the latest declassified information on technical developments (see Abstracts). In the exhibition hall, visitors saw displays ranging from cut-away rocket engine models to the latest style in protective clothing. Between times, members listened to featured speakers and fellow members make headlines.

Principal speaker at the fall meeting, Clifford C. Furnas, Assistant Secretary of Defense for Research and Development, sounded a conservative note on the future of space flight in his talk "Around the World in Ninety Minutes." After emphasizing the fact that the satellite program is an international scientific experiment and not for military purposes, Dr. Furnas said that man was approaching the time when he could start thinking of an unmanned satellite that would circle the moon and take pictures.

But it is not yet time, he added, for people to begin lining up even for one-way tickets to the moon. In fact, though there is a reasonable probability that an earth satellite will be launched in its orbit during IGY, Dr. Furnas emphasized, there is no assurance of success. Other newsmakers:

- Walter R. Dornberger of Bell Aircraft declared that a rocket vehicle capable of reaching the moon could be built with present technical know-how, fuels, and metals. But such a project, cautioned Dr. Dornberger, would not be practical at this time.

- Basing his forecast on Dr. Dornberger's expectations, Leston P. Faneuf, luncheon speaker and recently elected president of Bell, predicted that a manned space ship will make a return-trip to the moon by 1971.

- Another luncheon speaker and holder of the world speed record of 1900 mph, Lt. Col. Frank K. Everest asserted that but for lack of official interest and, consequently, research funds, man would now be flying at 7000 mph.

- And from some informal get-together at the meeting emerged word of two new high-altitude research rockets sponsored by the Navy and being developed by Atlantic Research Corp. (Alexandria, Va.). The first, a solid propellant rocket named Iris, is designed to carry a 100-lb load up to an altitude of 200 miles. The other, Arcon, will be smaller and less expensive, reach altitudes of 60 to 70 miles.

Abstracts

The following are summaries of all papers presented during the technical sessions of the recent ARS Fall Meeting (see above) held in Buffalo, Sept. 24–26. Full papers are available in preprints (see page 1028).

✦ Investigation of the Factors Affecting the Attachment of a Liquid Film to a Solid Surface, by C. F. Warner and B. A. Reese, Purdue University. (312–56)

In 1948, Jet Propulsion Center at Purdue initiated a fundamental investigation of film flow phenomena. In their paper, Reese and Warner summarize the experimental results on the film attachment phase of this investigation, present an empirical equation based on momentum exchange that correlates the experimental results with two- and three-dimensional flow fields.

✦ Some Considerations of Film Cooling for Rocket Motors, by M. J. Zucrow and A. R. Graham, Purdue University. (313–56)

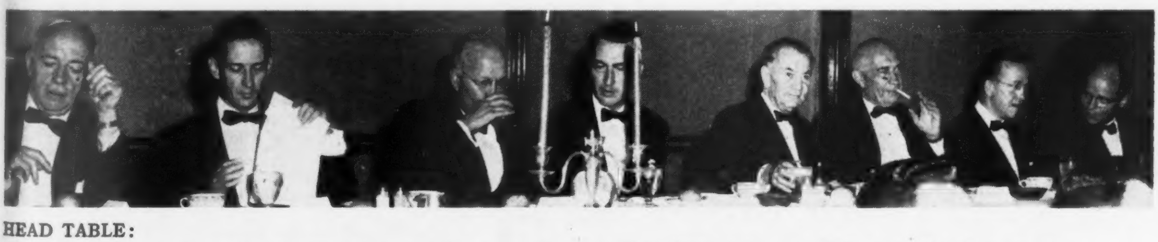
The authors take a semiempirical approach to the problem of film cooling rocket motors, present basic considerations pertinent to the film cooling of a circular duct. They show, for example, that due to instability of liquid film, the ideal film coolant flow requirements fall short of the actual requirements.

✦ Upper Bounds and Conservative Estimates for Aerodynamic Heating at Great Altitudes, by J. F. Vandrey, The Martin Co. (314–56)

Dr. Vandrey develops a simple procedure for obtaining upper bounds for aerodynamic heating at high speeds and altitudes. The procedure is based on energy considerations and assumes the most favorable flow conditions. In nonmarginal cases, such as the launching vehicle for an artificial satellite, these upper bounds result in skin temperatures low enough to serve as a guide for practical design purposes.

✦ The Recovery of High Speed Rocket Powered Vehicles and/or Their Components, by R. Provart, Cook Electric Co. (315-56)

Basic considerations of the recovery problem are presented and details peculiar to the types of components to be recovered are noted. The author discusses trajectory conditions, techniques of programming a



HEAD TABLE:
Walter Dornberger, Harry Ferullo, Claude Puffer, Ira Ross, Lawrence Bell, Clifford Furnas, William Smith, Noah Davis...

... Frank Everest, Robert Truax, F. H. Keast, James Vermilya, Wernher von Braun, V. Hwoshchinsky

recovery system, methods of sensing pertinent environmental conditions, and various braking devices. He also compares recovery systems, comments on current parachute technology and on devices and materials which appear promising for the future.

✦ Correlation of Ramjet Fuel Performance with Combustion Parameters, by H. F. Calcote of Experiment, Inc., and J. B. Fenn of Princeton University. (316-56)

Fenn and Calcote in this paper attempt to correlate ramjet fuel performance with combustion parameters so that the efficiency can be predicted from simple laboratory determinations.

✦ On the Development of Rational Scaling Procedures for Liquid-Fuel Rocket Engines, by S. S. Penner, California Institute of Technology. (317-56)

Author offers a critical summary of recent theoretical studies concerning similarity analysis and the scaling of liquid-fuel rocket engines. On the basis of this work, suggestions are offered for an experimental program on the development of rational scaling procedures.

✦ Similitude Considerations in Turbojet Engines, by S. Way, Westinghouse Electric Corp. (318-56)

The paper discusses physical similarity principles in flow and combustion systems, briefly considers the application of these principles to the separate engine components, and contains some observations concerning the turbojet engine as a whole.

✦ The Structure of Chlorine Flames, by R. F. Simmons and H. G. Wolhard, Royal Aircraft Establishment (England). (319-56)

Wolfhard and Simmons present the results of systematic studies of chlorine flames (i.e., flames produced using chlorine as the sole oxidant) as a preliminary toward a better understanding of the effect of chlorine compounds on combustion.

✦ Flame Stabilization in a Boundary Layer, by H. C. Hottel and Tau-Yi Toong of Massachusetts Institute of Technology, and J. J. Martin of Texas Co. (320-56)

In order to eliminate the difficulties involved in studying flame stabilization using a Bunsen flame, the authors, in a re-examination of the theory of flame stabilization, study the stability of a lean propane-air flame in the boundary layer along a water-cooled slender rod, with its longitudinal axis lying at the center line of a large Pyrex duct.

✦ Preliminary Evaluation of a Rotating Flame Stabilizer as a Means of Achieving Higher Heat-Release Rates per Unit of Combustion-Chamber Volume, by J. H. Grover, M. G. Kesler and A. C. Scurlock of Atlantic Research Corp. (321-56)

The authors discuss their evaluation of a rotating bluff flameholder, consider possible applications, and conclude from their experimental study that "other things being equal, the volumetric combustion efficiency of a high-output combustion chamber can be substantially increased by rotation of the flame stabilizer, and the combustion efficiency can be controlled by changing the rate of stabilizer rotation."

✦ Determination of Frequency Response of Accelerometers at Low Frequencies, by A. J. Amico and E. E. Greiner of Bell Aircraft Corp. (322-56)

Greiner and Amico offer a method developed by the Instrumentation Group at Bell Aircraft for accurate determination of the frequency response of accelerometers at frequencies below 12 cps and at any acceleration input up to 10 g.

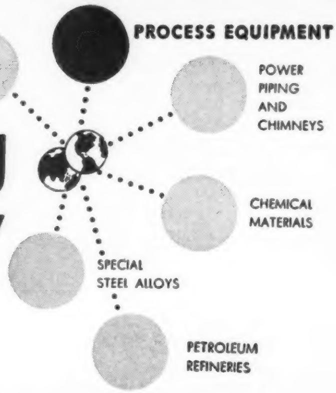
✦ Some Problems Associated with Instrumenting Shock Tubes for Hypersonic Research, by W. E. Smith and R. J. Vidal of Cornell Aeronautical Laboratory. (324-56)

The Defense that Research Built

Working closely with various government agencies and aviation companies*, The M. W. Kellogg Company has participated in many important research and development phases of the rocket program. This has covered a wide range of missiles and rocket propulsion systems for Terrier, Talos, Snark, Sparrow, and Nike. Kellogg has also produced booster rocket cases and other components.

M. W. Kellogg's long rocket experience, supplemented by this organization's 50-year background of engineering and fabricating high temperature-high pressure industrial products, continues to provide valuable assistance to National Defense.

*Including the Navy, Army, Air Force, Allegany Ballistics Laboratory, The Johns Hopkins University Applied Physics Laboratory, and such well-known aviation names as Bell, Boeing, Convair, Douglas, Grumman, Lockheed, McDonnell, Northrop, Republic.



M.W. Kellogg

ENGINEERING FOR TOMORROW

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This is a review of current practices and anticipated instrumentation developments, especially in the categories of pressure measurement and schlieren optics, as applied to hypersonic research activities at Cornell Aeronautical Laboratory.

✦ Some Advantages and Examples of Consolidated Test Equipment, by R. A. Shea, Allen B. DuMont Laboratories. (325-56)

The author advocates the consolidation of test equipment within one basic equipment group but cautions against exceeding the point of optimum consolidation. He suggests the factoring technique as the best approach.

✦ A Method for Optimizing Instrumentation Systems for Rocket Testing, by J. H. Zimmerman, North American Aviation Corp. (326-56)

By use of such mathematical techniques as Boolian algebra and linear programming, the author establishes a fairly flexible and general analytic model of an instrumentation system for static rocket testing, uses this model to optimize a simple instrumentation system, and then generalizes the methods for optimization of a complex rocket test facility.

✦ A Resistance Thermometer for Transient Surface Temperature Measurements, by R. J. Vidal, Cornell Aeronautical Laboratory, Inc. (327-56)

A recently developed resistance thermometer with a rise time of less than a microsecond is described and analyzed. Embodying a thin metallic film mounted on glass, it is used to measure transient surface temperatures on models in a hypersonic shock tunnel.

✦ Field Transportation of Concentrated Hydrogen Peroxide, by J. H. Keefe and C. W. Raleigh of Food Machinery and Chemical Corp. (328-56)

Raleigh and Keefe discuss methods of handling 90 per cent hydrogen peroxide commercially, outline requirements of hydrogen peroxide tactical service vehicles, and present examples of such tactical vehicles.

✦ The Physical and Chemical Properties of the Alkyl Hydrazines, by R. C. Harshman, Olin Mathieson Chemical Corp. (329-56)

In this paper, the author offers a compilation of data on the physical and chemical properties of a variety of alkyl hydrazines to show the general effects of substitution on properties.

✦ Unsymmetrical Dimethyl Hydrazine as a Starting Fluid for Nitric Acid-Jet Fuel Rocket Engines, by R. L. Potter and H. W. Byington of Bell Aircraft Corp. (330-56)

Byington and Potter discuss the data which led them to believe that UDMH is a superior starting fluid for nitric acid-jet fuel rocket engines.

✦ Chemical Aspects of Hypergolic Ignition for Liquid Propellant Rocket Engines, by L. R. Rapp and M. P. Strier of Reaction Motors, Inc. (331-56)

Authors describe a study on the relationship between chemical structure of the aliphatic amines and hypergolicity, deduce a general correlation between the chemical structure of the aliphatic amines and their ignition characteristics with white fuming nitric acid.

✦ Simulated Training for Rocket Aircraft, by J. N. Pecoraro, U. S. Naval Training Device Center. (333-56)

The presentation covers some problems of training personnel for rocket flight, describes various training devices developed to solve these problems.

✦ Some Experiments with Two-Dimensional Cavitating Venturis, by K. Berman of General Electric Co. and T. C. Carnavos of Griscom-Russell Co. (334-56)

Carnavos and Berman report on experimental work designed to study the effect of geometry on venturi operation and to explore capabilities and potentialities of venturis as flow controllers.

✦ Development and Manufacturing Problems of the Nike Thrust Chamber, by J. R. Piselli, Bell Aircraft Corp. (Preprint not available for distribution.)

This paper details various problems encountered during development of Nike thrust chamber, such as ceramic throat erosion, tells how the problems were solved.

✦ Explosive Actuated Valves for Guided Missiles, by M. W. Connell, Conax Corp. (336-56)

Author describes different explosive actuated valves, lists their reported advantages for use in missile systems.

✦ A Stationary Wave Resonant System to Produce High Sound Pressure Encountered in Missiles, by W. Fricke, Bell Aircraft Corp. (337-56)

Dr. Fricke's paper deals with the testing of sound-sensitive missile electronic components in a sound chamber developed by Bell Aircraft to simulate the noise spectrum of missiles.

Scouting Science Talent

LIKE the weather, the shortage of science graduates is a topic many people talk about and few do anything about. And when some one does do something about it, it's news.

Last spring, several ARS members led by Roy E. Marquardt, president of Marquardt Aircraft Co., organized the first experimental Science Explorer Post in cooperation with Boy Scouts of America.

The objective was to establish programs for young (14–17) men interested in scientific careers, catching them early enough so that their choice of school subjects could be influenced. The programs called for active participation in the following fields: nuclear energy, geology, and electronics. Each program was about a month long, consisted of discussion groups, field trips, and laboratory experiments—in addition to all the other traditional aspects of scouting.

Reporting on the first six months of operation, participating Marquardt scientists and engineers claim Science Explorer Post 501 has proved a highly successful experiment. This plan, they conclude, "shows that industrial sponsorship can provide the necessary leadership, enthusiasm, and equipment to intrigue and inspire young men into considering scientific careers."

Many other firms such as Rocketdyne and DuPont have expressed interest in this program, says Marquardt. And a second Science Explorer Post is already on its way, sponsored by North Texas Section of ARS under President George Craig.

Two More

Bringing the corporate total to 80, two new groups were recently accepted by ARS as duly qualified corporate members. They are:

• *Aviation Week.* A McGraw-Hill publication, *Aviation Week* is a weekly trade magazine that reports new developments in jet propulsion as part of

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its over-all coverage of the aviation field.

Staff members designated as corporate representatives: Robert W. Martin, publisher; Robert B. Hotz, editor; Alpheus W. Jessup, managing editor; Irving Stone, senior engineering editor; Evert Clark, associate news editor.

• Pacific Automation Products, Inc. Located in Glendale, Calif., the firm engineers and manufactures cable and electrical systems for guided missiles and rockets.

Representing the company as ARS members will be: Frank G. Jameson, president; Arthur P. Jacob, executive vice-president and general manager; Donald E. Studer, project engineer; Michael Rothbart, production manager; John J. Burke, secretary.

Sections

Columbus: On Sept. 11, the recently chartered Columbus Section held its first meeting of the fall season at Battelle Memorial Institute. Plans were made for the forthcoming year and the following Section officers were elected: M. W. Bell, president; R. E. Bowman, vice-president; K. O. Smith, recording secretary; L. E. Bollinger, corresponding secretary; G. A. Wright, treasurer; and, as directors, R. Edse, A. W. Lemmon, H. L. Johnston, and A. A. Putnam.

Florida: At its June 14 meeting, Florida also elected new Section officers. On the slate: V. O. Smith, president; R. L. Yordy, vice-president; R. H. Reynolds, treasurer; E. H. Munsey, program chairman; R. Rice, publicity chairman; J. Herbert, membership chairman; and, as directors, D. N. Yates, A. L. Conrad, R. B. Rypinski, G. C. Gentry, B. G. MacNabb, W. L. Risley, and R. S. Mitchell.

New York: The North Castle (N. Y.) Nike base held open house on Sept. 22 for about 200 Section members and guests. Officially designated Battery B, 66th Anti-Aircraft Artillery Missile Battalion, the base is commanded by Lt. Col. A. L. Meyer who talked about the Nike and its role in the defense of the New York area.

San Diego: Approximately 85 members and guests attended the August 23 meeting, listened to Section President Krafft Ehricke of Convair-Astronautics talk about the solar-powered space ship.

Noted mathematician George Gamow addressed the Section at its Sept. 5 meeting. About 185 members and friends listened to Professor Gamow review theories of planetary evolution and a new idea offered as a possible theory on the origination of life called global metabolism. He also discussed life on other planets and suspended animation as a proposed solution to the long travel time between planets.


Miniaturized
Radar Switchboard
Goes Down the Hatch
NOT THROUGH
THE HULL
They used to remove a section of the deck to get a radar switchboard inside a submarine. Now it fits easily through a hatch because Admiral has redesigned the unit to reduce bulk and weight by as much as two-thirds!
This priceless saving in pounds and inches is only one of the new unit's many advantages. Formerly up to 400 man-hours were needed for major repairs such as replacing a defective switch section. Now the job is done in 20 minutes! The entire unit is built up of standardized sub-assemblies fitted with multiple connector plugs. It is a simple matter to remove and replace a faulty switch or amplifier. Each switch section even has its individual power supply to keep the switchboard operable in case one section goes out. The unit can be readily expanded to handle additional radar indicators by simply adding more self-contained sections. Printed switches and circuit boards, designed for automation assembly, are ruggedly resistant to vibration and humidity.
The radar switchboard, for use on all types of naval vessels, is typical of Admiral's advanced design, research and development in electronics, now being carried forward for all branches of the Armed Services.
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New York Host to National Meeting

ABOUT to get underway, the 11th Annual Meeting will take place this year in New York from Nov. 26 through Nov. 29. Meeting headquarters will be the Henry Hudson Hotel.

As usual, highlight of the annual gathering will be the presentation of awards and fellowships to outstanding individuals in the jet propulsion field at the Honors Night Dinner on Nov. 29 (see 1956 ARS Awards Winners). Chief of Navy Bureau of Aeronautics, Rear Admiral James Russell, will be featured speaker at the dinner.

On the technical side, the meeting promises a solid and varied program of sessions ranging in scope from Rocket Production Techniques to Space Flight. (For a tentative listing of individual papers, see Annual Meeting Program.) Promising wide audience appeal, two sessions on high altitude sounding rockets will round up the latest unclassified information on sounding rockets here and abroad and will include a discussion of future sounding rockets as well.

A few blocks away from ARS headquarters and running concurrently with the Annual Meeting will be the 22nd National Exposition of Power and Mechanical Engineering at the Colesium. Of particular interest here to ARS members will be the Rockets & Missiles Section where companies such as Bendix Aviation, Cooper Development, Dow Chemical, Grand Central Rocket, General Electric, Hughes Aircraft, North American, Ramo-Wooldridge, RMI, Thiokol, etc., will display some of their latest wares in the missile field. (See page 1028.)

A well-rounded and interesting program overall, the 11th Annual Meeting promises to be a worthy climax for the 1956 ARS Meetings Calendar, a fitting invitation to next year's programs.

Annual Meeting Program

Monday, Nov. 26

9:30 a.m. Directors Meeting

3:00 p.m. Program Committee Meeting

Tuesday, Nov. 27

9:30 a.m. Solid Propellants

Chairman: W. L. Rogers, Aerojet-General Corp.
Vice-Chairman: Ivan Tuhy, Glenn L. Martin Co.

✦ Theory and Experiment on the Burning Mechanism of Composite Solid Propellants, by M. Summerfield and G. Sutherland, Princeton University. (360–56)

✦ Petroleum Based Solid Rocket Propellants, by J. A. McBride and R. W. Scharf, Phillips Petroleum Co. (338–56)

✦ Some Properties of a Simplified Model of Solid-Propellant Burning, by Leon Green, Jr., Aerojet-General Corp. (339–56)

✦ Some Preliminary Photoelastic Design Data for Stresses in Rocket Grains, by M. L. Williams, California Institute of Technology. (340–56)

9:30 a.m. Space Law and Sociology

Chairman: John Cobb Cooper, Princeton University and McGill University.
Vice-Chairman: Andrew G. Haley, Haley, Doty, and Wollenberg.

✦ A Study of the Rate Process of Life and Special Relativity Theory, by William R. Brewster, American Heart Association, Harvard University. (376–56)

✦ Projecting the Law of the Sea into the Law of Space, by Rear Admiral Chester C. Ward, Judge Advocate General of the United States Navy. (377–56)

✦ The Present-Day Developments in Space Law and the Beginnings of Metalaw, by Andrew G. Haley, Haley, Doty, and Wollenberg. (378–56)

✦ Some Social Implications of Space Travel, by Colonel William O. Davis, Air Force Office of Scientific Research. (379–56)

12:00 Noon Section Luncheon

2:30 p.m. High Temperature Materials

Chairman: George P. Sutton, North American Aviation, Inc.
Vice-Chairman: Leon Green, Jr., Aerojet-General Corp.

✦ Molybdenum for High Strength at High Temperatures, by R. R. Freeman, Climax Molybdenum Co. (341–56)

✦ Temperature Indicating Paints, by Jack Becker, Aerojet-General Corp. (342–56)

✦ Structural Materials for Missile Applications at Very High Temperatures, by J. R. Kattus, Southern Research Institute. (364–56)

✦ Graphite as a Material for High Temperature Gas Flow Systems, by Leon Green, Jr., Aerojet-General Corp. (382-56)

2:30 p.m. Combustion

Chairman: Arch C. Scurlock, Atlantic Research Corp.
Vice-Chairman: John F. Tormey, North American Aviation, Inc.

(Continued on page 1020)

New Award

ON NOVEMBER 29, Lt. General John B. Medaris, Commanding General of the Army Ballistic Missile Agency, will make the first presentation of the newly established Chrysler (Corporation) Award at the Honors Night Dinner, during the AMERICAN ROCKET SOCIETY'S 11th Annual Meeting in New York.

The award, this year, will go to James Blackmon, a student at Phillips Academy, for his "demonstration of imagination, initiative, and ingenuity in the field of missile rocketry," as shown by the 6-ft rocket Mr. Blackmon built in the basement of his home back in Charlotte, N. C.

The award carries a $1000 scholarship stipend, will be presented by the ARS on an annual basis. Complete details concerning future selection of candidates and presentations of the award will be reported in an upcoming issue of JET PROPULSION.


Chandler C. Ross


Donald Crabtree


Louis G. Dunn


Hermann Oberth


Joseph Kaplan


Bruce H. Sage

1956 ARS Awards Winners

G. Edward Pendray Award for rocket and jet propulsion literary effort goes to Hermann Oberth, author of many books and numerous technical reports in the jet propulsion field for his "Die Rakete zu den Planetenräumen" (Rocket to Interplanetary Spaces).

Professor Oberth was born 1894 in Hermannstadt, Transylvania. Before entering service in World War I, he had studied medicine in Munich. After the war, Professor Oberth took up mathematics and physics. He became, in succession, a high school teacher, a technical investigator, and then (1941–1943) a consulting engineer to Peenemunde.

After World War II, Professor Oberth came to the United States where he has served as a consulting engineer first to Redstone Arsenal and then to Army Ballistic Missile Agency.

ARS Astronautics Award for contribution to the advancement of space flight will be presented to Joseph Kaplan, chairman, U. S. National Committee for the International Geophysical Year.

Dr. Kaplan is a graduate of John Hopkins University (B.S., chemistry; M.A. and Ph.D., physics). After 10 years of teaching physics at University of California, Los Angeles, he became chairman of Physics Dept. in 1938.

From 1943 to 1945, Dr. Kaplan, on leave from UCLA, served as Chief of Operations Analysis Section of the Second Air Force and later of the Air Weather Service. Following World War II, Dr. Kaplan was appointed to the Air Force Scientific Advisory Board.

As head of U. S. National Committee for IGY, Dr. Kaplan is responsible for this country's program of geophysical research to be conducted in cooperation with other nations during 1957–1958.

James H. Wyld Memorial Award for outstanding application of rocket power will be given to Louis G. Dunn, vice-president and director of Guided Missile Research Div. of The Ramo-Wooldridge Corp.

Born in South Africa in 1908, Dr. Dunn became a naturalized U. S. citizen in 1943. After graduation from California Institute of Technology (B.S.; M.S., mechanical engineering; M.S., aeronautical engineering; Ph.D.), he stayed on first as a teacher and then, 1947 to 1954, as director of Cal Tech's Jet Propulsion Laboratory where he was in charge of developing the Corporal.

In 1954, Dr. Dunn left Cal Tech and joined Ramo-Wooldridge. In his present position as director of R-W's Guided Missile Research Div., he is responsible to the Air Force for systems engineering and technical direction of the USAF IRBM and ICBM programs.

C. N. Hickman Award for solid propellants goes to Bruce H. Sage, senior consultant for the Naval Ordnance Test Station, Inyokern, Calif.

Dr. Sage was born 1909 in State College, N. Mex. He attended New Mexico College of Agriculture and Mechanic Arts (B.S., chemical engineering) and California Institute of Technology (M.S., chemical engineering; Ph.D., mechanical engineering). After nine years of research and instruction at California Institute of Technology, Dr. Sage became professor of chemical engineering in 1944. In 1945, he was made head of NOTS explosives department. Four years later, Dr. Sage became associate director for engineering at NOTS and in 1950, senior consultant.

Robert H. Goddard Memorial Award for work in liquid propellants will be presented to Chandler C. Ross, manager of Aerojet-General Corp.'s Liquid Engine Div.

Mr. Ross was born 1913 in San Francisco. Graduated from the University of California (Berkeley) with a B.S. in mechanical engineering, he worked from 1936 to 1943 as chief engineer for various pump manufacturing firms, as a project engineer for a plant building company, served on University of California faculty and as a project engineer on Navy submarine pump projects.

In 1943, Mr. Ross joined Aerojet and immediately became associated with all of the company's major liquid engine programs. In addition to his principal job of division manager, Mr. Ross is a member of Aerojet's 107-A (Ballistics Missile) Advisory Committee and Large Solid Rocket Technical Advisory Committee.

ARS Student Award for the best student paper on rocket and jet propulsion will be given to Donald L. Crabtree, of Purdue University, for his paper on "Design Evaluation of One Type Nuclear Propulsion System."

Born in 1936 in Richmond, Ind., Mr. Crabtree, despite his age, is no stranger to honors and awards. While still in high school, he received honorable mention in the Westinghouse Science Talent Search and second place in the 1954 National Science Fair for his paper on "Heavy Water of Crystallization." Upon graduation, he was awarded an Honorable Merit Scholarship to Purdue.

At present, Mr. Crabtree is working as an undergraduate technician at Purdue's Jet Propulsion Center while studying for his bachelor's degree in mechanical engineering. When he gets his degree, he plans to enter graduate school and study at the Jet Propulsion Center.

Fellowships: In addition to the six award winners (above), the following eight people were selected by the Awards Committee to become 1956 Fellow Members of ARS:

Charles W. Chillson, chief research engineer, Curtiss Wright Corp., former ARS president (1952).

William C. House, principal engineer, Aerojet-General.

William H. Pickering, director, Jet Propulsion Laboratory, California Institute of Technology.

Simon Ramo, executive vice-president, The Ramo-Wooldridge Corp.

Maj. General Bernard Adolph Schriever, commander, Western Development Division, ARDC.

Russell K. Sherburne, chief physicist, Physical Science Lab., New Mexico College of Agriculture and Mechanic Arts; president, New Mexico–West Texas Section.

Fred S. Whipple, chairman, Department of Astronomy, Harvard University; director, Astrophysical Observatory of the Smithsonian Institute.

Maj. General Donald N. Yates, commander, Air Force Missile Test Center, ARDC, Patrick AFB.

The Editor Complains, Too

CONSIDER the editor. He weareth purple and fine linen. His abode is amongst the mansions of the rich. His wife hath her limousine and his first-born sporteth a racing car, that can hit her up in forty flat.

Lo! All the people breaketh their necks to hand him money. A child is born unto the wife of a merchant in the bazaar. They physician getteth ten gold plunks. The editor writeth a stick and a half and telleth the multitude that the child tippeth the beam a nine pounds. Yea, he lieth even as a centurion. And the proud father giveth him a Cremo.

Behold, the young one groweth up and graduateth. And the editor putteth into his paper a swell notice. Yea, a peach of a notice. He telleth of the wisdom of the young woman, and of her exceeding comeliness. Like the roses of Sharon is she and her gown is played up to beat the band. And the dressmaker getteth two score and four iron men.

The daughter goeth on a journey. And the editor throweth himself on the story of the farewell party. It runneth a column, solid. And the fair one remembereth him from afar off with a picture post card that costeth a jitney.

Behold, she returneth and the youth of the city fall down and worship. She picketh one and Lo, she picketh a lemon. But the editor calleth him one of the most promising young men and getteth away with it. And they send unto him a bid to the wedding feast and behold, the bids are fashioned by Muntgummery Hawbuck, in a far city.

All flesh is grass and in time the wife is gathered into the silo. The minister getteth his bit. The editor printeth a death notice, two columns of obituary, three lodge notices, a cubit of poetry, and a card of thanks. And he forgetteth to read proof on the head, and the darned thing cometh out "Gone to Her Last Roasting Place."

And all that are akin to the deceased jumpeth on the editor with exceeding great jumps. And they pulleth out their ads and cancelleth their subscriptions and they swing the hammer unto the third and fourth generations.

Canst thou beat it?

Editors Note: This editorial is reprinted from the San Clemente (Calif.) Sun, by permission. Although the problems of the editor described herein are not the same as ours, there is a universality of editorial problems that prompts us to publish it here.

✦ Radiation Intensity from Highly Turbulent Flames, by R. A. John and M. Summerfield, Princeton University. (343–56)
✦ Analysis of Combustor Performance Based on Simplified Chemical Kinetics, by Ernest Mayer, ARDE Associates. (344–56)
✦ Investigation of Behavior and Reaction Mechanism of Nitric Acid–Hydrocarbon Flames, by M. H. Boyer and P. E. Friebertshauser, Rocketdyne Division of North American Aviation. (371–56)
✦ Use of the Moliere Type Thermodynamic Charts for Calculating Performance and Design Parameters, by Charles H. Trent, Aerojet-General Corp. (373-56)
✦ Industrial Applications of the Rocket Principle, by F. R. Job, Linde Air Products Co. (350–56)

7:00 p.m. Annual Business Meeting

Wednesday, Nov. 28

9:30 a.m. High Altitude Sounding Rockets—I
Chairman: Homer E. Newell, Jr., Naval Research Laboratory.
Vice-Chairman: John W. Townsend, Naval Research Laboratory.
✦ The Sounding Rocket in the IGY Program by Homer E. Newell, Jr., Naval Research Laboratory. (345–56)
✦ Aerobee-Hi, by John W. Townsend, Naval Research Laboratory; and Bob Slavin, Air Force Cambridge Research Center. (346–56)
✦ The Nike-Cajun Sounding Rocket, by Les Jones, University of Michigan; William Stroud, Evans Signal Laboratory; Nelson Spencer, University of Michigan; and Warren Berning, Ballistic Research Laboratory. (361–56)
✦ Future Sounding Rockets, by W. C. House, E. R. Roberts, R. Waldo, W. T. Cox, and C. Dodge, Aerojet-General Corp. (347–56)

9:30 a.m. Liquid Propellant Rockets
Chairman: C. C. Ross, Aerojet-General Corp.
Vice-Chairman: Robert B. Dillaway, North American Aviation, Inc.
✦ Importance and Application of Thrust Control for Liquid Propellant Rockets, by R. H. Reichel, Bell Aircraft Corp. (348–56)
✦ Dynamic Characteristics of a Liquid Filled Tube, by W. A. Sibley and W. G. Oakes, Boeing Airplane Co. (349–56)
✦ An Approximate Theory for Discharge Coefficients of Flow Nozzles, by F. S. Simmons, Rocketdyne Division of North American Aviation. (351–56)
✦ A Philosophy for Improved Rocket Nozzle Design, by R. B. Dillaway, Rocketdyne Division of North American Aviation. (362–56)

2:30 p.m. High Altitude Sounding Rockets—II
Chairman: Martin Summerfield, Princeton University.
Vice-Chairman: Robert A. Gross, Fairchild Engine and Airplane Corp.
✦ ASP (Atmosphere Sounding Projectile), by James A. Van Allen, State University of Iowa; and Cliff Cooper, Cooper Development Corporation. (352–56)
✦ The NAvy Rockaire Program, by John Masterson, Office of Naval Research. (380–56)
✦ The Air Force Rockaire Program, by Robert Slavin, Air Force Cambridge Research Center. (381-56)
✦ The Veronique Sounding Rocket, by Etienne Vassy, University of Paris. (353–56)
✦ Japanese Sounding Rockets, by Hideo H. I. Itokawa, University of Tokyo. (363–56)
✦ British Sounding Rockets, by E. B. Dorling, Royal Aircraft Establishment. (373–56)

2:30 p.m. Atomization and Sprays
Chairman: Thomas Meloy, General Electric Co., AGT Division.
Vice-Chairman: Fred W. Garry, General Electric Co.
✦ Instrumentation to Measure Composition

and Temperature of High Velocity, Two-Phase, Two-Component Flows, by K. R. Wadleigh and R. A. Oman, Massachusetts Institute of Technology. (354–56)

✦ Theoretical and Experimental Study of the Deformation and Atomization of a Liquid Drop in a High Velocity Gas Stream, by Naotsugu Isshiki Masugi, Ministry of Transportation, Tokyo, Japan. (355–56)

✦ On the Atomization of Liquid by Means of Flat Impingement, by Yasusi Tanasawa, Tohoku University, Sendai, Japan. (356–56)

8:00 p.m. New York Section Film Night

Thursday, Nov. 29

9:30 a.m. Space Flight Symposium

Chairman: Krafft Ehricke, Chairman, ARS Space Flight Committee, Convair.

Vice-Chairman: Darrell C. Romick, Goodyear Aircraft Corp.

✦ Some General Considerations of the Utility and Operation of a Long Range Manned Rocket Research Vehicle, by G. H. Stine, White Sands Proving Ground. (357–56)

✦ Heat Transfer to Satellite Vehicles Re-Entering the Atmosphere, by N. H. Kemp, and F. R. Riddell, Avco Research Laboratory. (358–56)

✦ Lifetime of Artificial Satellites of the Earth, by Irvin G. Henry, Aerojet-General Corp. (359–56)

✦ Skin Temperatures of a Satellite, by Craig Schmidt, Bell Aircraft Corp. (383–56)

✦ A New Type of Nuclear Power for Space Flight, by R. L. Carroll, Naval Air Test Center. (375–56)

9:30 a.m. Rocket Production Techniques—I

Chairman: Albert G. Thatcher, Reaction Motors, Inc.

Vice-Chairman: James Fitzgerald, Reaction Motors, Inc.

✦ Important Factors of Rocket Engine Development with a Foresight on Mass Production, by Guenther W. A. Haase, Bell Aircraft Corp. (365–56)

✦ Redstone Missile Assembly Problems, by Charles W. Williams, Chrysler Corp. (366–56)

✦ Design and Production of the Falcon Solid Propellant Motor Case, by Carl E. Johnson, Scaife Co. (368-56)

2:30 p.m. Reliability

Chairman: R. P. Haviland, General Electric Co.

✦ Reliability Concepts in Rocket Power Control Design, by H. L. Coplen, Jr., Aerojet-General Corp. (369–56)

✦ Methods for Measuring, Analyzing, and Predicting Reliability and Performance of Large Complex Electronic Systems, by Richard R. Landers, General Electric Co. (367–56)

✦ Sequential Analysis as a Practical Method of Satisfying Reliability Requirements, by William Brewington, Reaction Motors, Inc. (384-56)

✦ Designing Equipment for Reliability, by R. B. Wilson, Convair. (374–56)

7:00 p.m. Honors Night Dinner

Speaker: Rear Admiral James Russell, chief, Navy Bureau of Aeronautics.

ARS Meetings Calendar

Nov. 26–29: ARS Annual Meeting, Henry Hudson Hotel, New York. Honors Night Dinner on Nov. 29. Speaker: Rear Admiral James S. Russell, chief, Bureau of Aeronautics.

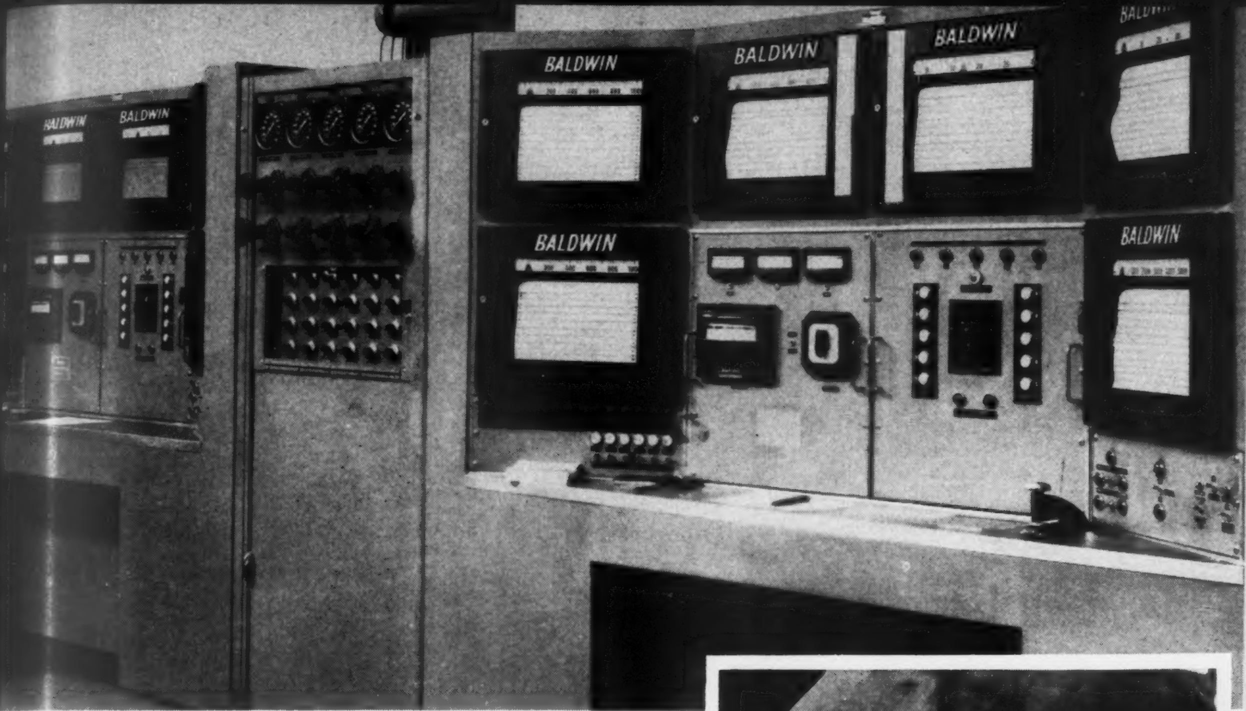
—1957—

March 18–20: ARS Spring Meeting, Hotel Statler, Washington, D. C.

June 9–13: ARS Semi-Annual Meeting, Hotel St. Francis, San Francisco.

Aug. 25–28: ARS–Northwestern Technological Institute Gas Dynamics Symposium, Northwestern University, Evanston, Ill.

Dec. 2–6: ARS Annual Meeting, New York.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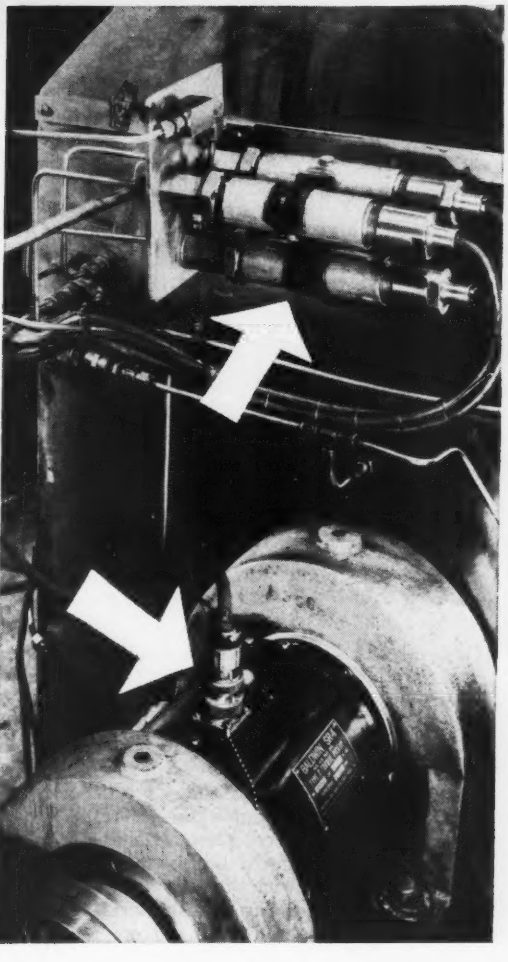

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SPECIAL EXHIBIT

ON

ROCKETS AND MISSILES

UNDER THE AUSPICES OF ARS

AT THE

22nd NATIONAL EXPOSITION OF POWER AND MECHANICAL ENGINEERING

NOVEMBER 26—30

COLISEUM, NEW YORK

(Across the street from ARS 11th Annual Meeting at the Henry Hudson Hotel)

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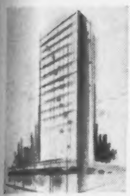

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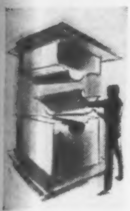

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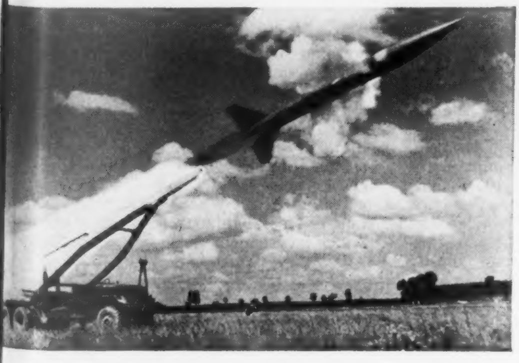


▲ **ARMY PACKAGE POWER REACTOR,** now under construction at Fort Belvoir, Va., will be completed in early 1957. ALCO is prime contractor. APPR has been designed so that all components can be transported by air to remote areas for installation.

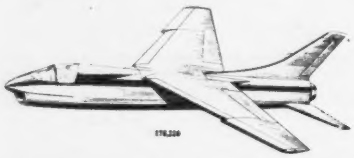
New Patents

George F. McLaughlin, *Contributor*

Air Swirler surrounding fuel nozzle discharge end (2,752,753). Philip G. Dooley, Bolton, Conn., assignor to United Aircraft Corp.

Swirler comprising an inner and outer ring with cambered vanes between, and adapted to impart a vortical motion and increased velocity to air passing between the rings.

Retractable mount for rockets (2,752,824). Miles J. Mraz, Cicero, Ill., assignor to North American Aviation, Inc.



Airplane design (178,220). John R. Clark, Lyman C. Josephs III, and Conrad A. Lau, Dallas, Tex., assignors to Chance Vought Aircraft, Inc.

This design patent for a high wing jet fighter is the basis for Vought's F8U-1 Crusader, the Navy's fastest interceptor. The leading edge of the variable incidence wing can be raised to increase the attack angle; therefore, the plane takes off and lands with wing high and nose low, giving the pilot good visibility. It is especially adapted for carrier operations. Announcement was made in September that the Crusader set an official U. S. speed record of 1015.428 mph.

Self-propelled missile (2,752,850). Arthur W. Warner and William B. McLean, China Lake, Calif.

Liquid propellant (2,753,683). Don R. Carmody, Crete, Ill., assignor to Standard Oil Co.

An injection comprising triethyltrithiophosphite and an oxidizer of nitromethane and anhydrous nitric acid.

Time delay fuze for a rocket (2,754,759). Kenneth L. Baker and Carl A. Axelson, Washington, D. C.

Pair of booster charges and an arming member within the casing supported in a safe position, and adapted to be moved to an armed position when released. A firing plunger is moved to the firing position upon impact of the rocket with a target.

Air intake system for an aircraft (2,755,040). Alfons M. Pinkos, Norman E. Wilson, and Robert W. Schroeder, Oak Ridge, Tenn., assignors to The Glenn L. Martin Co.

Rocket motor (2,755,620). R. Y. Gillot, Paris, France, assignor to Societe Nouville des Establissments Brandt.

An annular block of propellent within an elongated tubular casing, and an inner block of propellant disposed within and spaced from the block. One of the blocks is tapered rearwardly at its combustion surface.

Rotating flow combustor [in a jet engine] (2,755,623). Antonio Ferri and Ira R. Schwartz, Baltimore, Md.

Means for stabilizing fuel burning in an annular flow passage by imparting rotary motion to the fuel-air mixture before it reaches the flameholder.

Rocket generator power supply (2,755,737). Allen S. Clarke, Washington, D. C., assignor to the War Dept.

Rocket fuse (2,755,738). Harry G. Jones, Jr., Casper J. Koeper, and Francis P. Gilhooly, Huntsville, Ala., assignors to the U. S. Army.

Gas turbine engine with axial-flow compressor and bearing means for supporting the compressor rotor (2,756,561). F. W. Morley, Castle Donington, England, assignor to Rolls-Royce, Ltd.

Retractable arbor missile projector (2,756,634). Herbert Allen, Madden T. Works, and Marvin R. Jones, Houston, Tex., assignors to the U. S. Navy.

Aircraft launching device, including a rocket-propelled ball screw and nut (2,756,950). Raymond E. Greenough, Berea, Ohio, assignor to The Cleveland Pneumatic Tool Co.

Rotational motion between screw threaded elements moved by a tangentially mounted jet motor provides relative axial motion producing forces for assisting aircraft in takeoffs.

Wingless aircraft design (178,410). Alexander M. Lippisch, Cedar Rapids, Iowa, assignor to Collins Radio Co..

Details of the design indicate that air enters the front of the body and is deflected downward by a series of vanes under the body extending from about the center of gravity to the vertical rudder.

Thrust reversal and variable orifice for jet engines (2,753,684). William L. Greene, Colesville, Md., assignor to ACF Industries, Inc.

Gas turbine engine with exhaust gas heating means (2,753,685). Donald H. Mattinson, Derby, England, assignor to Rolls-Royce, Ltd.

Ramjet fuel regulator (2,753,686). Louis S. Billman, Glastonbury, Conn., assignor to United Aircraft Corp.

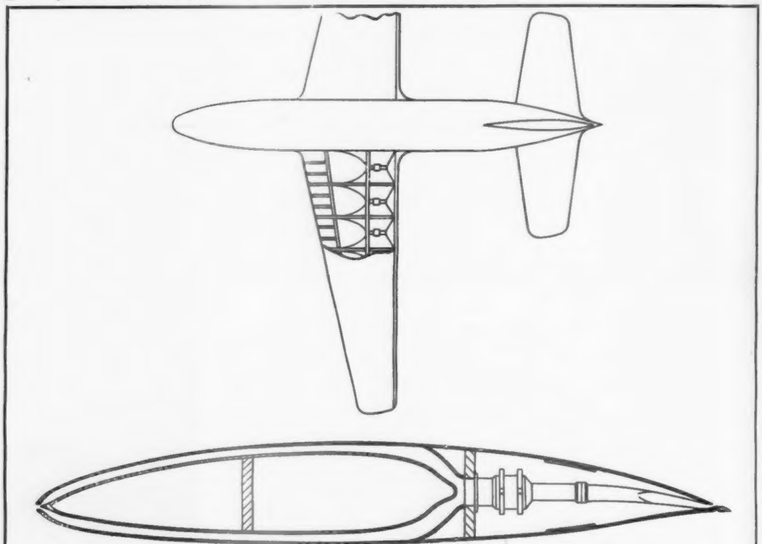
Injection head for jet propulsion system (2,753,687). Zoltan R. Wissley and George L. MacPherson, Scotia, N. Y., assignors to General Electric Co.

Combination liquid and solid propellent rocket (2,753,801). Joseph M. Cumming, San Marino, Calif.

Liquid propellent chamber forward of a perforated partition within the body, and discharging through the perforations into the combustion chamber. A solid propellant is secured to the partition and discharged directly into the combustion chamber.

Fuel control means for aerial jet-propelled bodies (2,753,882). Charles H. Bottoms, Simonstone, England, assignor to Joseph Lucas, Ltd.

Thrust cylinder with integrated turbine (2,754,655). Hans T. Holzwarth, Westfield, N. J., assignor to The M. W. Kellogg Co.



Jet propelled aircraft with wing-mounted jet engines (2,756,008). Ivor M. Davidson, Farnsborough, England, assignor to Power Jets (Research and Development) Ltd.

In this design, several jet engines are separately mounted side-by-side between the wing spars. Engines can be readily detached and removed for inspection, repair, or replacement. Separate shallow ducts for each engine extend along the wing leading edge, and discharge is through long flattened nozzles at the trailing edge, from wing tip to wing tip. The jet flow may be deflected upward or downward by increasing or decreasing the angular attitude of a narrow flap hinged at the trailing edge.

Recent independent American investigations of means to suppress jet noise indicate that an exhaust in the form of a long thin slit would result in appreciable noise reduction. The idea is substantiated by the new "slit exhaust" (rectangular trailing edge type) which has reduced noise in the Convair 440 Metropolitan.

Editor's Note: The patents listed above were selected from recent issues of the Official Gazette of the U. S. Patent Office. Printed copies of patents may be obtained at a cost of 25 cents each, from the Commissioner of Patents, Washington 25, D. C.

Book Reviews

Ali Bulent Cambel, Northwestern University, *Associate Editor*

The Men Behind the Space Rockets, by Heinz Gartmann, David McKay Co., Inc., New York, 185 pp. $3.95.

Reviewed by S. F. Singer
University of Maryland

Mr. Gartmann offers a very readable, nontechnical account of the early history of space flight. He concentrates mainly on the leading personalities responsible for the present development of the space flight field. There is, for example, a chapter each on Ganswindt, Tsiolkovski, Goddard, Oberth, Valier, Sänger, Zborowski, and Wernher von Braun. The book contains an abundance of pictures and many personal anecdotes and stories which this reviewer, at least, has not seen published before. To sum up: Very light but interesting.

Aeroelasticity, by Raymond L. Bisplinghoff, Holt Ashley, and Robert L. Halfman, Addison-Wesley Co., Inc., Cambridge, Mass., 1955, ix + 860 pp. $14.50.

Reviewed by E. E. Sechler
California Institute of Technology

This book is an encyclopedic collection of the many subjects underlying the all-encompassing field of aeroelasticity. As the name implies, aeroelasticity is essentially the coupling of aerodynamic and elastic systems; however, since in the broadest sense both of these systems may be dynamic as well as static, both static elasticity and vibrations must be considered as well as static and dynamic aerodynamic forces. With the addition of the necessary mathematical knowledge to properly treat the various problems, the task of writing a textbook attempting to cover the entire field in one volume is a difficult one. The authors of the present textbook have accomplished this task in an admirable manner.

The organization of this book is logical, going as it does from the relatively simple to the complex in each of the subjects treated. Starting with a treatment of the structural or elastic tools in Chaps. 2 through 4 (Chap. 1 is a general introduction to the subject), the authors begin by establishing the background equations of static elasticity and then proceed to discuss the problem of deformations under dynamic loading conditions. At all times the emphasis is on the application of these principles to airplane structural configurations, such as wings, fuselages, and tail surfaces. Many examples are worked out in detail in order to illustrate methods which have previously been discussed in general terms.

The treatment of the underlying structural tools is followed by a similar review of the aerodynamic tools, presented in Chaps. 5, 6, and 7. Again, going from the simple to the difficult, the work starts with two-dimensional incompressible flow and gradually proceeds through three-dimensional incompressible flow, into simple compressible flow phenomena, and finally discusses wings and bodies in three-dimensional, unsteady, compressible flow.

With the groundwork now laid, the authors begin to integrate the problems of elasticity and aerodynamics by first treating static aeroelastic phenomena (Chap. 8), simple flutter (Chap. 9), and finally the subject of dynamic response (Chap. 10).

In the first ten chapters, the authors have shown that many of the theoretical equations are difficult, if not impossible, to solve exactly. This raises the question of obtaining solutions by experimental methods and this problem is treated in the remaining three chapters of the book. Chap. 11 covers aeroelastic model theory; Chap. 12, model design and construction; and Chap. 13 outlines various testing techniques both for full scale and model scale systems.

Finally, an appendix gives a very short outline of some of the required mathematical tools, such as matrices, integration by weighting numbers, and linear systems.

A mere review of the subject matter covered in a book of less than 900 pages indicates that the material must be highly condensed. For this reason, this is not a book particularly suited to the person who wants a broad descriptive picture of the subject of aeroelasticity but it is much more suited to the mature engineer who already has a sound background knowledge of mathematics (including matrices and complex function theory), elasticity, vibrations, and aerodynamics (including compressible flow theory). For such a person, the book will be an extremely valuable condensation of the present state of knowledge of this new science; in addition, it offers a comprehensive bibliography of the literature on the subject that will permit the serious investigator to pursue any single phase of the subject to any degree of detail desired.

The three authors of the book are eminently suited for the task they have so successfully undertaken. They have all been associated with a group at MIT that has been engaged in the study of aeroelastic phenomena ever since flutter was found to be important in aircraft design and, furthermore, has pioneered in the experimental techniques designed to obtain aeroelastic data from wind tunnel models, as well as full scale flight testing. They have presented the state of the art in an extensive and critical manner, not only outlining what is known, but in many cases also indicating where knowledge is limited and where more theoretical and experimental research is called for. Even though detailed applications and techniques may be expected to change rapidly in the next few years (as is always the case in a new field), the basic principles covered in this textbook will make it a valuable reference source for any engineer or scientist interested in aeroelastic phenomena as applied to aircraft.

Linearized Theory of Steady High Speed Flow, by G. N. Ward, Cambridge University Press, 1955, 243 pp. $6.

Reviewed by ALFRED RITTER
Armour Research Foundation
Illinois Institute of Technology

The linearized theory of high speed flows has received considerable attention by aerodynamicists and mathematicians, both here and abroad, during the past ten years, and recently a large portion of this work has been summarized, e.g., Ward, Temple in "Modern Developments in Fluid Dynamics," vol. I, 1953, and Sears, Heaslet and Lomax in "High Speed Aerodynamics and Jet Propulsion," vol. VI, 1954. The present monograph is a worthy addition to the current literature and presents a unified approach to the problem of steady, linearized high speed flows. The text is divided into three parts, and in the first part, on general theory, an attempt has been made to develop logically the linear theory for steady flows giving particular attention to the underlying assumptions. The equations of motion for an inviscid, nonconducting fluid are considered, and the genesis of linearized theory is discussed and applied to rotational as well as irrotational flows. Extensive use has been made of vector notation throughout this development. The general solutions of the linearized equations for subsonic and supersonic flow are presented. Uniqueness of solution is discussed briefly and the concept of the "finite part" (Hadamard, 1923) of a divergent integral is introduced. Concluding this first part on general theory is a chapter devoted to boundary conditions, aerodynamic forces, uniqueness, and flow reversal theorems.

The second part, on special methods, considers briefly the subsonic flow past thin bodies, including the well-known Prandtl-Glauert rule. However, the treatment of the supersonic flow past wings of finite span is rather detailed and follows earlier developments by Evvard. A chapter on the linearized theory of supersonic conical flow fields is included and follows the treatment of Goldstein and Ward (1950). To conclude the section on special methods, a chapter is devoted to the Heaviside operational method in the solution of the flow past axially symmetric ducts of nearly constant radius wherein the meridian section has small slopes relative to the tube axis on both external and internal surfaces.

Rounding out the text is the section on slender body theory. The linearized potential for subsonic and supersonic flow past a body of revolution is derived and extended to include flows past more general bodies. Forces and moments are calculated with applications to bodies of revolution, plane wings of low aspect ratio, and winged bodies of revolution. Concluding the section is the treatment (Lighthill, 1948) of the supersonic flow past a body of revolution wherein the slope of the meridian cross section is discontinuous.

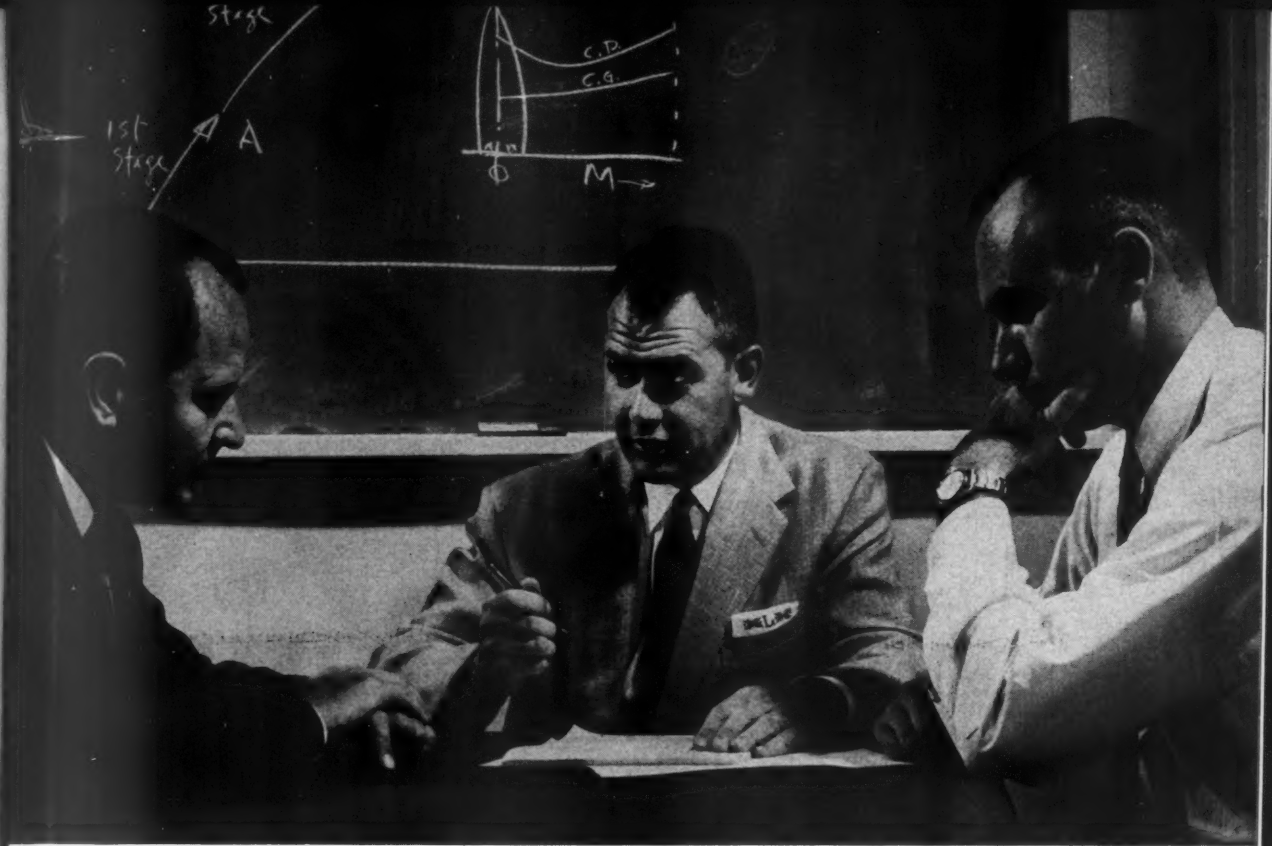
This monograph is definitely not a textbook, but rather a concise presentation of the more important aspects of linearized theory. It is intended for use by aerodynamicists and mathematicians who are working on the problems of high speed flow, and the excellent bibliography of some 200 entries should be quite helpful.

Book Notices

Jet Engine Manual, by E. Mangham and A. Peace, Philosophical Library, New York, 1955, 133 pp. $3.75. This volume is written for those who are engaged in the operation and maintenance of turbojet and turbopropeller engines. The practical aspects of the subject are emphasized in a concise manner.

Fundamental Formulas of Physics, edited by Donald H. Menzel, Prentice-Hall, New York, 1955, 765 pp. This volume is an excellent handbook of fundamentals presented in the most concise manner. Each chapter is written by an author known for his own contributions to the field. This compilation includes the aspects of physics which are of interest to the propulsion engineer.

Du Wirst die Erde sehn als Stern, by Wolfgang D. Müller, Deutsche Verlags-Anstalt, Stuttgart, Germany, 1955, 316 pp. DM 14.80. The author discusses the nontechnical problems of space flight for the layman. He enters into the realms of philosophical speculations concerning the future of mankind and life on other planets. Although the book is of popular nature and emphasizes some of the more romantic aspects, it is interesting and not misleading.



L. K. Edwards (center), advanced design and systems analysis department head, discusses launching of a ballistic missile with W. P. Gruner (left), head of weapons systems integration, and Systems Analyst G. W. Flynn.

TECHNOLOGICAL

AERONAUTICAL SYSTEMS have made vital contributions to the progress of jet avi- tion and its expansion into the civil transport field. Ma- have won recognition as the finest in the industry, benc- marks of American technology.

Whole generations of airmen, for instance, ha- been trained in flight simulators developed and produc- by Link, pioneer of on-the-ground flight training. T- GPE Company has delivered over 800 jet flight sim- lators—more than all other manufacturers put togeth- It has just been selected, on the basis of superior tec- nology and equipment, to produce America's first sim- lators for jet air liners. Link-developed DC Comput- Systems in Link supersonic simulators are the only on- meeting the needs of these advanced aircraft.

Equally dominant are the gyro-magnetic compa- systems of Kearfott, another GPE Company. This com- pany's new lightweight J-4 Compass System weighs on-

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BENCH MARKS

ounds. Yet it provides accurate heading information l latitudes, is rugged enough to maintain its high ac-cy despite the jolts and speeds of jet flight. The Air ce has just selected it as standard for all new fighter t. Kearfott's N-1 Compass System has been the navi-onal standard for Air Force bombers for 5 years.

Still another member of the GPE Group, General ision Laboratory, has developed and is currently ing quantity deliveries of the most advanced airborne igation systems in use. These GPL systems, which self-contained and fully automatic, have flown mil-s of operational miles with unprecedented accuracy. ir adaptations to civilian jet needs—GPL's RADAN tems—are expected to make equally far reaching con-utions to the commercial jet transport field—in the y of increased safety, fuel economy, passenger conven-e and efficient use of limited air space.

These are but some of the accomplishments in avia-tion for which GPE Companies, working in conjunction with the Armed Services, are responsible. Librascope, an important member of the Group, produces outstanding instruments and equipment for the field. Librascope's computers, its highly advanced equipment for photo-reconnaissance work and photogrammetric equipment for the interpretation of photo data, its periscopes, pilot and navigator finders, are all leaders. Several GPE Com-panies are deeply involved in inertial guidance, guided missile projects and certain nuclear power applications.

In all GPE achievements in the numerous industries in which the companies work, GPE Coordinated Preci-sion Technology plays an important part by inter-relating the wide range of skills and resources of the Group. This operating policy, and each company's unremitting in-sistence on highest quality, are major reasons for the fre-quency with which GPE systems and equipment continue to set standards in their fields.

QUIPMENT CORPORATION

GPE GROUP *Ampro Corporation • Askania Regulator Company • Bizzelle Cinema Supply Corporation • Bludworth Marine*
Precision Laboratory Incorporated • The Griscom-Russell Company • The Hertner Electric Company • International Projector Corporation
Kearfott Company, Inc. • Librascope, Incorporated • Link Aviation, Inc. • J. E. McAuley Mfg. Co. • National Theatre Supply
Pleasantville Instrument Corporation • Precision Technology, Inc. • SEC-o-matic Corporation • Shand and Jurs Co.
Society for Visual Education, Inc • The Strong Electric Corporation • Theatre Equipment Contracts Corporation

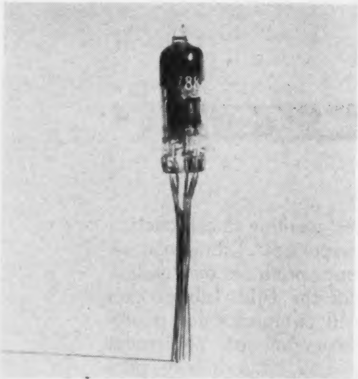
New Equipment and Processes

Equipment

Electrical, Electronic

Missile Fire Control. Automatic opening of rocket pods, launchers, etc.; secures on airframe. Abrams Instrument Corp., 606 E. Shiawasse St., Lansing 1, Mich.

Power Supply. For missile, rocket use, this dc to dc transistorized unit weighs 2 lb, delivers 50 w from 24 v input. Universal Atomics Corp., 19 E. 48 St., New York 17, N. Y.



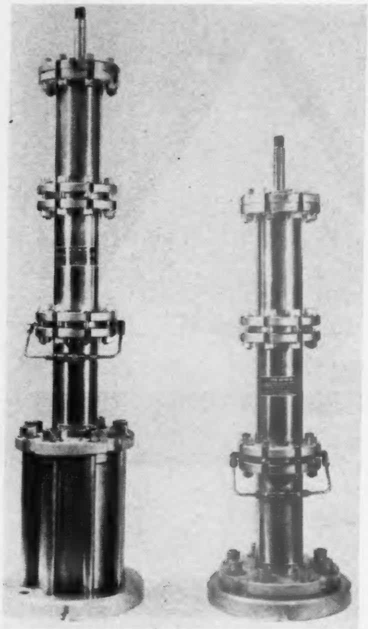
Guided Missile Tubes. Subminiature series includes pentodes and triodes. Sylvania Electric Products, 1740 Broadway, New York 19, N. Y.

Explosive Igniters. Wide line for igniters or pressure-actuated systems. McCormick Selph Associates, 62 Hollister Airport, Hollister, Calif.

Pancake Rectipot. Model 86125A is a miniature spring-loaded linear motion potentiometer. Stroke range of 0.1–0.5 in. at 1000 and 2000 ohm. For fire control systems. G. M. Giannini & Co., 918 E. Green St., Pasadena 1, Calif.

Test

Pulse Camera. Bell & Howell 200-P has pulse length of 30 ms for $^1/_{100}$ sec exposure. Built-in heater. 50-ft magazine, 16 mm. Triad Corp., 4515 Sepulveda Blvd., Sherman Oaks, Calif.



Dynamic Shock Testing. Hyge Actuator simulates high loads, delivers 12,000-lb thrust. Modular units provide adaptability to many tests. Consolidated Electrodynamics Corp., Rochester Div., 1775 Mt. Read Blvd., Rochester 3, N. Y.

Radiation Pyrometers. IR-2 for measurements in 60–1300 C range, IR-1 to 1000 C. Servo Corp. of America, 20-20 Jericho Turnpike, New Hyde Park, L. I., N. Y.

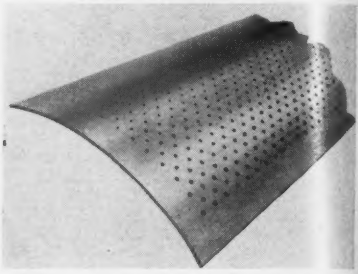
Digital Flow Rate Indicator. Direct-reading, in-line, integrated. Specific gravity range of 0.5 to 1.5. Fisher & Porter Co., 785 Jacksonville Rd., Hatboro, Pa.

Temperature Indicator. Scale of −100 to 600 F and 300–900 C with thermocouples. Features $^1/_2$% accuracy and 0.8-sec full scale response. Handley Electronics, 14758 Keswick St., Van Nuys, Calif.

Rectilinear Recorder. Direct writing 6-in. strip recorder; 1 ma gives full scale ($4^1/_2$-in.) deflection in $^1/_4$ sec. 2 cps undamped frequency. 100-ft chart with speeds of in./min. or in./hr. Houston Technical Labs., 370 Buffalo Speedway, Houston 6, Tex.

Materials

Protected Wire Assemblies. Scinseal polyvinyl chloride plastisol. Fused at 300–350 F. Gives flexible seals for leads and junctions. Scintilla Div., Bendix Aviation Corp., Sidney, N. Y.



Porous Metal Sheet. Varaperf sheets are available in wide variety of metals, sizes, and gages. BLC Porous Materials Co., 1955 Lafayette St., Santa Clara, Calif.

Titanium. Corrosion-resistant in sheet and bars, pure or alloyed. Mallory-Sharon Titanium Corp., Niles, Ohio.

Honeycomb. Stainless steel, resin bonded with cell sizes $^3/_{16}$ to $^3/_8$ in. Densities of 3.4–12.6 lb/ft^3. Hexcel Products, 951 Sixty-First St., Oakland 8, Calif.

MOLYBDENUM PROGRESS

After seven years on a Navy-sponsored major research and development program on molybdenum-base alloys for high-temperature applications, materials engineers gathered in Detroit on Sept. 18 to compare notes.

Among other things, they learned that various coatings to protect molybdenum surfaces from oxidation—the most serious drawback to high temperature use of the metal—are under development, and recent work indicates that coatings to permit operation at temperatures of 1800 F to 2000 F may be near at hand.

Too, they heard that molybdenum alloys had already been developed which retain useful strength properties up to at least 2000 F and that engineers are now working on alloys and protective coating which can operate at temperatures considerably above 2000 F.

Applications of molybdenum and molybdenum-base alloys, of course, are not confined to aircraft and weapons. But military interest very definitely lies in their potential as construction materials for such high temperature applications as jet engine and missile parts.

Current alloys are approaching the maximum limit of performance, says Office of Naval Research; and the higher temperatures at which aircraft and weapons of advanced design must operate call for better materials. Molybdenum alloys, ONR feels, could be the answer.

Technical Literature Digest

M. H. Smith, *Associate Editor,* **and M. H. Fisher,** *Contributor*
The James Forrestal Research Center, Princeton University

Heat Transfer and Fluid Flow

Experimental Investigation of Air-Cooled Turbine Blades in Turbojet Engine. XI. Internal-Strut-Supported Rotor Blade, by Reeves P. Cochran, Francis S. Stepka and Morton H. Krasner, *NACA RM* E52C21, June 1952, 45 pp. (Declassified from Confidential, *NACA Research Abstracts* no. 102, June 22, 1956, p. 16.)

Experimental Investigation of Air-Cooled Blades in Turbojet Engine. XII. Cooling Effectiveness of a Blade with an Insert and with Fins Made of a Continuous Corrugated Sheet, by Edward R. Bartoo and John L. Clure, *NACA RM* E52F24, Aug. 1952, 33 pp. (Declassified from Confidential, *NACA Research Abstracts* no. 102, June 22, 1956, p. 16.)

Composition Change in Binary Component Spray Vaporization at Atmospheric Pressure, by J. F. Culverwell and P. W. Grounds, Jr., *Project Squid Tech. Rep.* NTI-63-P, March 1956, 14 pp. (Available only on microcard.)

Three Dimensional Flow Through an Axial Compressor, by J. Valensi, *Univ. D'Aix-Marseille Inst. Mech. Fluides, Quart. Rep.* 7, Feb. 28, 1955, 28 pp. (ASTIA AD-80, 176).

Approximation Equations for Circulation Distribution Around Closely Spaced Blades in a Cascade, by A. Betz, *Zeitschr. Flugwiss.*, vol. 4, May–June 1956, pp. 166–169 (in German).

Velocity Discontinuity Instability of a Liquid Jet, by B. Dunne and B. Cassen, *J. Appl. Phys.*, vol. 27, June 1956, pp. 577–582.

Pulse Testing a Model Heat Exchange Process, by Sidney Lees and Joel O. Hougen, *Indust. Engng. Chem.*, vol. 48, June 1956, pp. 1064–1068.

Dynamic Characteristics of Double-Pipe Heat Exchangers, by William C. Cohen and Ernest F. Johnson, *Indust. Engng. Chem.*, vol. 48, June 1956, pp. 1031–1034.

Predicting Dynamics of Concentric Pipe Heat Exchangers, by J. M. Mozley, *Indust. Engng. Chem.*, vol. 48, June 1956, pp. 1035–1041.

On the Wake Energy of Moving Cascades, by N. H. Kemp and W. R. Sears, *J. Appl. Mech.*, vol. 23, June 1956, pp. 262-268.

Heat Transfer of a Laminar Pipe Flow with Coolant Injection, by S. W. Yuan and A. B. Finkelstein, *Project Squid Tech. Rep.* PIB-27-P, March 1956, 9 pp. (Available only on microcard.)

Cooling of Ram Jets and Tail Pipe Burners—Analytical Method for Determining Temperatures of Combustion Chamber Having Annular Cooling Passage, by William K. Koffel, Eugene Stamper, and Newell D. Sanders, *NACA RM* E9L09, Sept. 1949, 51 pp. (Declassified from Confidential, *NACA Research Abstracts* no. 101, May 25, 1956, p. 9.)

Kinetic Energy of Relative Motion, by Joseph O. Hirschfelder and John S. Dahler, *J. Chem. Phys.*, vol. 24, June 1956, pp. 1258.

Heat Transfer Between Solid Particles and Gas in a Rocket Nozzle, by Peter L. P. Dillon and Lloyd E. Line, Jr., *Experiment, Inc.*, TP-101, April 1956, 31 pp.

Analysis of Viscous Incompressible and Compressible Flows Through Axial Flow Turbo-Machines with Infinitesimal and Finite Blade Spacing, by T. Paul Torda, *Wright Air Dev. Center Tech. Rep.* 55–231, March 1956, 105 pp.

The Solution of Steady State Heat Conduction Equation with Chemical Reaction for the Hollow Cylinder, by J. W. Enig, *Navord Rep.* 4267, April 1956, 8 pp.

Flow of Gas Through Turbine Lattices, by M. E. Deich (translated from Russian book *Technical Gasdynamics*, 1953, Ch. 7, pp. 312–420). *NACA TM* 1393, May 1956, 136 pp.

A Study of the End Wall Boundary Layer in an Axial Compressor Blade Row, by Raymond W. Moore, Jr., and David L. Richardson, *Massachusetts Inst. Tech. Gas Turb. Lab. Rep.* 33, Oct. 1955, 19 pp., 34 figs.

Combustion

The Measurement of the Sensitivity, Time Lag of Explosion and Burning Velocity of Explosives by Drop Test Techniques, by T. K. Collins and M. A. Cook, *Utah Univ. Tech. Rep.* 48 on Adiabatic Decomposition of Explosives, Dec. 15, 1955, 55 pp.

Generalized Equations and Procedures for the Calculation of Detonation Parameters. Case 1. Ideal Gaseous Mixtures, by Robert G. Dunn and Bernard T. Wolfson, *Wright Air Dev. Center TN* 54–13, March 1956, 79 pp.

Ignition of Double Base Propellants by Detonating Gases, *Utah Univ. Inst. for the Study of Rate Processes, Explosives Res. Group, Tech. Rep.* 5, Nov. 1955, 21 pp.

The Oxidation of Lower Paraffin Hydrocarbons. Part II. Observations on the Role of Ozone in the Slow Combustion of Isobutane, by C. C. Schubert and Robert N. Pease, *Project Squid Tech. Rep.* PR-65-P, April 1956, 12 pp. (Available only on microcard.)

Flame Properties and the Kinetics of Chain Branching Reactions, by J. Calvin Giddings and J. O. Hirschfelder, *Wisconsin Univ. Naval Res. Lab. Rep.* Squid-5, May 1956, 31 pp.

Burning Rate Studies. Part 9. Variation of Surface Temperature with Pressure for Burning Liquids, by D. L. Hildenbrand and A. Greenville Whittaker, *Navord Rep.* 1999, Part 9, (NOTS 1402), March 1956, 6 pp.

Burning Rate Studies. Part 10. Variation of Temperature Distribution with Consumption Rate for Burning Liquid Strand, by D. L. Hildenbrand and A. Greenville Whittaker, *Navord Rep.* 1999, Part 10, (NOTS 1403), March 1956, 6 pp.

A Contribution to the Application of Flame Photometry on Ca, Sr, Ba and Li, by T. J. Hollander, A. J. Borgers, and C. T. J. Alkemade, *Appl. Sci. Res. Section B*, vol. 5, on. 6, 1956, pp. 409–427.

Calculation of the Detonation Properties of Solid Explosives with the Kistiakowsky-Wilson Equation of State, by R. D. Cowan and W. Fickett, *J. Chem. Phys.*, vol. 27, May 1956, pp. 932–939.

Flame Theory and Combustion Technology, by Frank E. Marble, *J. Aeron. Sci.*, vol. 23, May 1956, pp. 462–468.

Spark Ignition of Flowing Gases, Itsuro Kimura and Seiichiro Kumagai, *J. Phys. Soc. of Japan*, vol. 11, May 1956, pp. 599–604.

Fuels, Propellants, and Materials

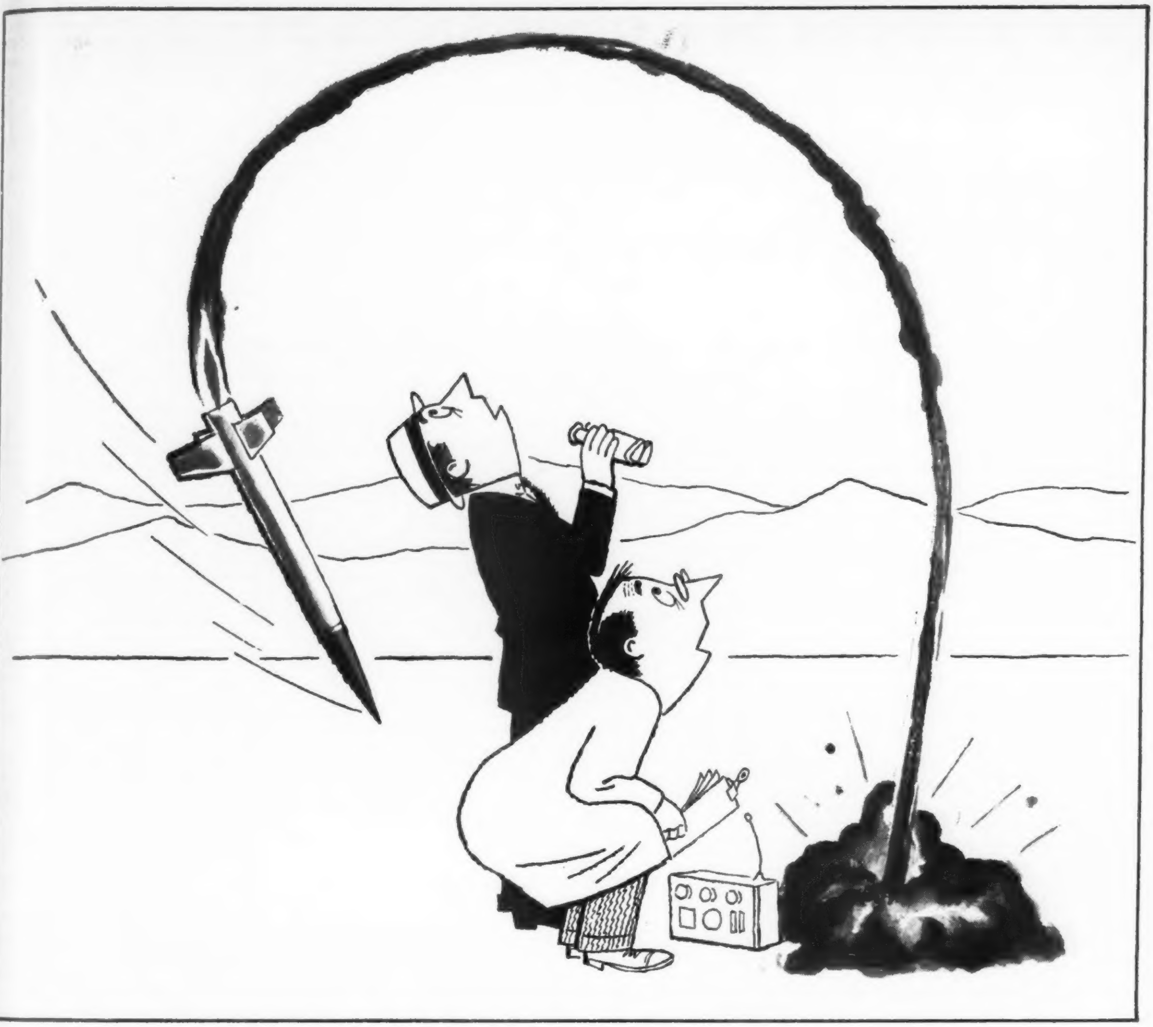
Rocket Refractories, by Harry B. Porter, *Navord Rep.* 4893 (NOTS 1191), Aug. 1955, 44 pp.

Correlation Between Laboratory and Engine Performance of Synthetic Turbine Lubricants, by T. F. Davidson and J. H. May, *SAE Prepr.* 755, June 1956, 7 pp.

Optical Properties of Metals, by L. G. Schulz, *Wright Air Dev. Center Tech. Rep.* 55–71, March 1956, 39 pp.

Energetics of the Boranes. I. The Heats of Reaction of Diborane with the Methylamines, and of Tetramethyldiborane with Trimethylamine; the Dissociation Energy of Diborane, by R. E. McCoy and S. H. Bauer, *J. Amer. Chem. Soc.*, vol. 78, May 1956, pp. 2061–2065.

National Annual Survey of Aviation Fuels, 1955, by O. C. Blade, *Bur. Mines Info. Circ.* 7747, March 1956, 15 pp.



Investigation of the Effect of Impact Damage on Fatigue Strength of Jet-Engine Compressor Rotor Blades, by Albert Kaufman and André J. Meyer, *NACA TN* 3275, June 1956, 25 pp.

Experimental Investigation of Air-Cooled Turbine Blades in Turbojet Engine. XIV. Endurance Evaluation of Shell-Supported Turbine Rotor Blades Made of Timken 17-22a(S) Steel, by Francis S. Stepka, H. Robert Bear, and John L. Clure, *NACA RM* E54F23a, Sept. 1954, 29 pp. (Declassified from Confidential, *NACA Research Abstracts* no. 102, June 22, 1956, p. 18.)

Instrumentation and Experimental Techniques

Transmitters for Measuring Temperature of High Speed Gas Flow, by S. G. Darevsky, *Doklady Akad. Nauk SSSR,* vol. 107, no. 3, 1956, pp. 373–376 (in Russian).

A Corrected Speed Tachoscope, by R. Staniforth, *Gt. Brit. Aeron. Res. Council Curr. Pap.*, no. 224 (formerly *Nat. Gas Turb. Estab. Mem.*, no. 217), 1956, 9 pp.

The Dall Flow Tube, by I. O. Miner, *Trans. ASME,* vol. 78, April 1956, pp. 475–479.

A Sonic-Flow Orifice Probe for the Inflight Measurement of Temperature Profiles of a Jet Engine Exhaust with Afterburning, by C. Dewey Havill and L. Stewart Rolls, *NACA TN* 3714, May 1956, 18 pp.

A Survey Meter with an Extended Probe, by C. E. Flanagan, Jr., and R. T. Nowak, *Atomic Energy Comm.* DP-142, Dec. 1955, 8 pp.

Fluid Interface Monitoring by Capacitance Probe Method, by C. A. Simsen, *Atomic Energy Comm.* HW-39170, Sept. 1955, 21 pp.

Test Equipment, Section G. Research and Development Trends; Magnetic Tape is Key to Flight Test System; Jet Accessories Pose Testing Challenge, *Aviation Age*, vol. 25, June 1956, pp. Y-3–Y-10.

Computers, Section H. Research and Development Trends; Analog Computers in Modern Aircraft Design; How Aircraft Industry Uses Computers (Table); Computers for the Aircraft Industry (Table), *Aviation Age*, vol. 25, June 1956, pp. H-3–H-17.

A New Method for the Measurement of Rapid Fluctuations of Temperature, by R. Dehn, *Brit. J. Appl. Phys.*, vol. 7, April 1956, pp. 144–148.

Dynamics of Liquid Flow Control, by Allan R. Catheron and Bruce D. Hainsworth, *Indust. Engng. Chem.*, vol. 48, June 1956, pp. 1042–1046.

A New Computer for Calculating the Water Content of Gases, by A. W. Diniak and E. R. Weaver, *J. Res. Nat. Bur. Stands.*, vol. 56, May 1956, pp. 269–278.

Capacitor Type Fuel Gages and Controls, by Sanford Solars, *Aero Digest*, vol. 72, June 1956, pp. 26–29.

Space Flight, Astrophysics, Aerophysics

Rocket and Satellite Studies During the IGY, by Joseph Kaplan, *Aeron. Engng. Rev.*, vol. 15, April 1956, pp. 64–67.

Boiling and Density Studies at Atmospheric Pressure, by D. English, P. T. Blacker, and W. E. Simmons, *Gt. Brit. Atomic Energy Res. Estab. A.E.R.E.* ED/M 20, 1955, 13 pp.

U. S. Army Photo

AA Fire Control System T50 mounted on "Duster", the Army's twin 40mm self-propelled vehicle M42. This is a major advance in control of fire for this weapon.

FRANKFORD ARSENAL IS ARMY'S CENTER FOR ORDNANCE WEAPONS FIRE CONTROL SYSTEMS

This "Old Line" Arsenal in Philadelphia is a key member of the Army-Ordnance-Industry team. Since World War II it has been rapidly converting from a manufacturing installation to a research and development center responsible for national direction or major support of Ordnance ammunition and weapons programs, chemical, metallurgical, and ballistic research, and gage design and supply.

The major operating organizations of Frankford are the Pitman-Dunn Laboratories Group, the Ammunition Group, the Gage Laboratory, and the Fire Control Instrument Group. The latter is a small arsenal in itself, consisting of research and development, industrial procurement and production, and field service elements. Working with weapons systems contractors in private industry, its scientists and engineers have been responsible for successful application of optical range finders to tanks, for the Skysweeper AA System and the AA Fire Control System M33. Today, Frankford maintains close relations with the Army Ballistic Missile Agency and Redstone Arsenal for the solution of guidance problems. Recently this group has applied radar ranging to the twin 40mm self-propelled light AA gun, the "Duster", enlarging this weapon's capabilities for dealing with high-speed, low flying aircraft.

That segment of industry interested in fire control instruments, ammunition components, and recoilless weapons relies for definition of the problem, and allocations of programs, on Frankford Arsenal, whose goal has been defined as Total Technical Teamwork.

This is one of a series of ads on the technical activities of the Department of Defense.

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